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**Environmental Considerations of Selected
Energy Conservation Manufacturing Process
Options. Vol. I. Industry Summary Report**

Arthur D. Little, Inc., Cambridge, Mass.

Prepared for

Industrial Environmental Research Lab, Cincinnati, Ohio

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**ENVIRONMENTAL
CONSIDERATIONS OF
SELECTED ENERGY
CONSERVING MANUFACTURING
PROCESS OPTIONS:
Vol. I Industry Summary
Report**

Interagency
Energy-Environment
Research and Development
Program Report

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EPA-600/7-76-034a
December 1976

ENVIRONMENTAL CONSIDERATIONS OF SELECTED
ENERGY CONSERVING MANUFACTURING PROCESS OPTIONS

Volume I

INDUSTRY SUMMARY REPORT

EPA Contract No. 68-03-2198

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study, consisting of 15 reports, identifies promising industrial processes and practices in 13 energy-intensive industries which, if implemented over the coming 10 to 15 years, could result in more effective utilization of energy resources. The study was carried out to assess the potential environmental/energy impacts of such changes and the adequacy of existing control technology in order to identify potential conflicts with environmental regulations and to alert the Agency to areas where its activities and policies could influence the future choice of alternatives. The results will be used by the EPA's Office of Research and Development to define those areas where existing pollution control technology suffices, where current and anticipated programs adequately address the areas identified by the contractor, and where selected program reorientation seems necessary. Specific data will also be of considerable value to individual researchers as industry background and in decision-making concerning project selection and direction. The Power Technology and Conservation Branch of the Energy Systems-Environmental Control Division should be contacted for additional information on the program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

EXECUTIVE SUMMARY

This project has examined 13 energy-intensive industrial manufacturing segments from the standpoint of identifying environmental impact of energy-conserving changes in processes or practices with high probability of being implemented during the next 10 to 15 years. Changes possible without major process modification, such as improved housekeeping and thermal efficiencies, were not considered. Within the context of the project, conservation was considered achievable by two possible routes: direct thermal savings and also savings in the domestically more scarce energy forms by switching direct-fired fuels and feedstocks from natural gas and light petroleum streams to heavier petroleum fractions and coal.

Within each industry segment, several of the more probable processes were selected for detailed analysis and were compared to a conventional technology base case. Over 80 conventional and new process alternatives were evaluated.

Although actual process changes are expected to occur slowly on the average, specific changes at specific sites could occur at any time, including the immediate future, and could require EPA regulatory attention. The most serious environmental problems will result from switching to direct-fired fuels and feedstocks containing higher concentrations of sulfur and other components that will lead to greater quantities of SO_x , NO_x , particulates, toxic materials, and sludges. Options that would lead to both energy savings (Btu's) and environmental benefits were also identified. Examples of these options are given in Table ES-1. The need for more cost effective pollution control, for better instrumentation, and for health effect studies were stressed.

First and second-level priorities for research, development, and demonstration can be placed on areas in each industry examined as has been done in Table ES-2. In the context of this study, the industries of greatest need of environmental technology RD&D are iron and steel, petroleum refining, aluminum, and pulp and paper. Of the remaining industries included in the table, all require additional environmental RD&D, except for chloralkali and fertilizer mixing, which are judged to be industries for which adequate control technology is available.

Generic technologies which cross several industries were also identified where RD&D efforts should be placed. These areas of generic technology consist of: preheating of feedstocks, sulfur removal from hot gases, fluidized bed technology, heat recovery, NO_x emission control, use of oxygen rather than air for more efficient process combustion or reaction, application of electric furnaces, and use of solvent-based rather than aqueous-based processes.

TABLE ES-1

EXAMPLES OF ENERGY-CONSERVING (FEWER BTU'S) PROCESS TECHNOLOGY
HAVING POTENTIALLY SMALLER POLLUTION CONTROL COSTS

- Aluminum (Volume VIII*)
 - Alcoa chloride
- Cement (Volume X)
 - Suspension preheater/flash calciner
- Chloralkali (Volume XII)
 - Dimensionally stable anodes with microporous or ion exchange membranes
- Copper (>90% sulfur recovery) (Volume XIV)
 - Noranda smelting process
 - Flash smelting
- Glass (Volume XI)
 - Preheating/batch agglomeration
- Iron and Steel (Volume III)
 - Collection of CO gases from Basic Oxygen Process
 - External desulfurization of blast furnace pig iron
- Phosphoric Acid (detergent grade) (Volume XIII)
 - Cleanup of wet acid by neutralization/precipitation
- Phosphoric Acid via Strong Acid Process (Volume XIII)
- Pulp and Paper (Volume V)
 - Rapson effluent free process
 - Alkaline-oxygen process
- Textiles (Volume IX)
 - Advanced aqueous processing

*Volume numbers refer to individual reports from the project.

TABLE ES-2

AREAS FOR RESEARCH AND DEVELOPMENT IN POLLUTION CONTROL

	Iron & Steel (Volume III)	Petroleum Refining (Volume IV)	Pulp & Paper (Volume V)	Dierfine (Volume VI)	Nitrocellulose (Volume VII)	Aluminum (Volume VIII)	Textiles (Volume IX)	Cement (Volume X)	Glass (Volume XI)	Chlor-Alkali (Volume XII)	Phosphorus (Volume XIII)	Copper (Volume XIV)	Fertilizers (Volume XV)
<u>Air</u>													
Fine particulate removal technology. This would include especially those particulates resulting from metallic smokes and sublimed substances such as Mercury, arsenic, zinc, etc.	1	1	1		1	1		1	1		1	1	1
Collection or control of fugitive emissions from process equipment	1	2	2	2	1	1	1	2			2	1	1
Better definition of the environmental and biological impacts of the following emissions with respect to obtaining more quantitative knowledge for establishing emission regulations.													
a. Gases such as SO _x , NO _x , CO, F, Cl, NH ₃	1	1	1	2	1	1		1	1	1		1	
b. Metallic smokes	1	2		2	1	1		1	1			1	
c. Organic compounds that have high smog characteristics or carcinogenic aspects	1	1	2	1		1	1						
Odor Control		1	1	2									
Improved instrumentation for rapid monitoring and recording of airborne emissions	1	2	1			1		2	1			1	
<u>Water</u>													
Better definition of the environmental and biological impact of substances which cannot be removed by best available technology economically achievable. This will include, principally, metals and organic compounds that have long biological half-lives or carcinogenic effects.	1	1	1		1	1					1	1	
Suspended solids removed from treated wastewaters	1	1	1		1	2		2		2	1	2	
Removal of refractory organic compounds not achievable by technologies now designated as BATEA by EPA	1					2	1						
Color removal		2	1				1						
Removal of dissolved metals	1	2				1			2	2	1	2	
Improved instrumentation for rapid monitoring and recovery of waterborne pollutants	1		1	2	2		2				2		
<u>Solid Wastes</u>													
Demonstration of adequate landfill disposal techniques	1	1	2	2	2	1	2	1	2	2	1	2	
Demonstration of thermal destruction technologies	2	1	2	1		1				2			
Research into the methods of categorization, regulation and legal methodologies for controlling the disposal of solid wastes	1	1	2	1	1	1	2	1	1	2	1	1	1

(1) Denotes First Level Priority

(2) Denotes Second Level Priority

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Dr. Herbert S. Skovronek, Project Officer, was a valuable resource to us throughout the study. He not only supplied us with information on work presently being done in other branches of EPA and other government agencies, but served as an indefatigable guide and critic as the study progressed. His advisors within EPA, FEA, DOC, and NBS also provided us with insights and perspectives valuable for the shaping of the study.

During the course of the study we also had occasion to contact many individuals within industry and trade associations. Where appropriate we have made reference to these contacts within the various reports. Frequently, however, because of the study's emphasis on future developments with comparative assessments of new technology, information given to us was of a confidential nature or was supplied to us with the understanding that it was not to be credited. Therefore, we extend a general thanks to all those whose comments were valuable to us for their interest in and contribution to this study.

Finally, because of the broad range of industries covered in this study, we are indebted to many people within Arthur D. Little, Inc. for their participation. Responsible for the guidance and completion of the overall study were Mr. Henry E. Haley, Project Manager; Dr. Charles L. Kusik, Technical Director; Mr. James I. Stevens, Environmental Coordinator; and Ms. Anne B. Littlefield, Administrative Coordinator.

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ENGLISH-METRIC (SI) CONVERSION FACTORS

<u>To Convert From</u>	<u>To</u>	<u>Multiply By</u>
Acre	Metre ²	4,046
Atmosphere (normal)	Pascal	101,325
Barrel (42 gal)	Metre ³	0.1589
British Thermal Unit	Joule	1,055
Centipoise	Pascal-second	0.001
Degree Fahrenheit	Degree Celsius	$t_c = (t_F - 32)/1.8$
Degree Rankine	Degree Kelvin	$t_K = t_R/1.8$
Foot	Metre	0.3048
Foot ³ /minute	Metre ³ /sec	0.0004719
Foot ³	Metre ³	0.02831
Foot ²	Metre ²	0.09290
Foot/sec	Metre/sec	0.3048
Foot ² /hr	Metre ² /sec	0.00002580
Gallon (U.S. liquid)	Metre ³	0.003785
Horsepower (550 ft-lbf/sec)	Watt	745.7
Horsepower (electric)	Watt	746.0
Horsepower (metric)	Watt	735.5
Inch	Metre	0.02540
Kilowatt-hour	Joule	3.60×10^6
Litre	Metre ³	1.000×10^{-3}
Micron	Metre	1.000×10^{-6}
Mil	Metre	0.00002540
Mile (U.S. statute)	Metre	1,609
Poise	Pascal-second	0.1000
Pound force (avdp)	Newton	4.448
Pound mass (avdp)	Kilogram	0.4536
Ton (assay)	Kilogram	0.02916
Ton (long)	Kilogram	1,016
Ton (metric)	Kilogram	1,000
Ton (short)	Kilogram	907.1
Tonne	Kilogram	1,000

Source: American National Standards Institute, "Standard Metric Practice Guide," March 15, 1973. (ANSZ2101-1973) (ASTM Designation E380-72)

I. INTRODUCTION

In many industrial sectors significant reductions in energy usage can be achieved by better maintenance and housekeeping (e.g., shutting off standby furnaces, automatic thermostat control, elimination of steam and heat leaks, and the like) and greater emphasis on the optimization of energy usage. Because of shortages or risk of shortages of a specific fuel form, economic pressures, changes in feedstocks, and the like, further improvements in energy conservation can be expected from the introduction of new industrial processes. Such process alternatives will undoubtedly result in changes in air, water, and solid waste discharges.

Process changes introduced by the major industrial sectors can indeed impact energy consumption because industry accounts for about 40% of total energy use (when electric power use is allocated to the various industry sectors), as shown in Table 1. The other 60% or so of energy use can be attributed to the household/commercial segment and the transportation sector. Table 2 shows that five industry groups accounted for about three-quarters of the total energy consumption in the manufacturing sector as follows:

- The Primary Metals Industry group (SIC 33) accounted for 25% of total manufacturing energy used.
- The Petroleum and Coal Products group (SIC 29) accounted for about 16 to 18%, depending on whether electricity is valued on a thermal equivalent or fossil fuel basis.
- The Chemical and Allied Products group (SIC 28) accounted for about 17-18%.
- The Paper and Allied Products group (SIC 26) accounted for about 8%.
- The Stone, Clay, and Glass Products group (SIC 32) accounted for about 8%.

Each of these industry sectors has experienced environmental problems of one type or another. The nature of these problems can be expected to change as industry introduces new processes and implements new technology for a variety of reasons including efforts to reduce energy use or the use of certain fuel forms.

TABLE 1

DISTRIBUTION OF ENERGY CONSUMPTION BY SECTOR (1971)

Sector	Purchased Fuels		Purchased Fuels Plus Electricity* Valued on Thermal Basis		Purchased Fuels Plus Electricity** Valued on Fossil Fuel Basis	
	10 ¹² Btu	%	10 ¹² Btu	%	10 ¹² Btu	%
Industrial						
-Manufacturing	14,329	20.8	16,085	27.9	19,732	28.8
-Non-Manufacturing	5,965	8.6	6,538	11.7	7,728	11.3
Total Industrial	20,294	29.4	22,623	39.6	27,460	40.1
Household/Commercial	14,281	20.7	17,441	30.6	24,006	35.0
Transportation	16,971	24.6	16,989	29.8	17,026	24.9
Electrical Generation	17,443	25.3	-	-	-	-
Total	68,989 [†]	100.0	57,053	100.0	68,492 [†]	100.0

* Purchased electricity valued at its thermal equivalence of 3,412 Btu/kWh and allocated to consuming sectors.

** Purchased electricity valued at an approximate fossil fuel equivalence of 10,500 Btu/kWh and allocated to consuming sectors.

[†] Totals would be equivalent if all electric energy were generated from fossil fuels at a rate of 10,500 Btu/kWh.

Source: FEA, Project Independence, Blueprint, Vol. 3, November 1974, and Arthur D. Little, Inc. estimates.

TABLE 2

DISTRIBUTION OF ENERGY CONSUMPTION WITHIN THE MANUFACTURING SECTOR (1971)

Five Energy Intensive Manufacturing Industries	Purchased Fuels only		Purchased Fuels and Electricity Valued on Thermal Basis ^(*)		Purchased Fuels and Electricity Valued on Fossil Fuel Basis ^(**)	
	10 ¹² Btu	%	10 ¹² Btu	%	10 ¹² Btu	%
(F) Primary Metals Industry	3,613	25.2	4,030	25.1	4,896	24.8
(2) Chemicals & Coal Products	2,443	17.0	2,783	17.3	3,489	17.7
(3) Petroleum & Coal Products	2,877	20.1	2,956	18.4	3,120	15.8
(4) Paper & Allied Products	1,196	8.3	1,315	8.2	1,562	7.9
(5) Stone, Clay & Glass Products	1,291	9.0	1,367	8.5	1,525	7.7
Total of Five	11,420	79.6	12,451	77.5	14,592	73.9
Other Manufacturing	2,909	20.3	3,634	22.6	5,140	26.0
Total Manufacturing	14,329	99.9 ^(†)	16,085	100.1 ^(†)	19,732	99.9 ^(†)

(*) Purchased electricity valued at its thermal equivalence of 3,412 Btu/kWh.

(**) Purchased electricity valued at an approximate fossil fuel equivalence of 10,500 Btu/kWh.

(†) Failure to sum to 100% due to rounding error.

Source: FEA Project Independence Blueprint, Vol. 3, November 1974. Based largely on purchased fuels except for primary metals industries and petroleum and coal products where captive consumption of energy from byproducts is included.

Thus the purpose of this study was to address the environmental/energy impacts of new technology by:

- defining the environmental/energy implications of new process technology in key industry sectors;
- assessing the implementability of such new technology;
- alerting the EPA to areas where its activities and policies could influence the choice of process alternatives;
- identifying processes demanding additional research and development in order to
 - a) provide further information on pollutant loads or environmental consequences, or
 - b) provide economically viable pollution control techniques.

The focus of the study was based on examining potential alternative technology in new facilities. In addition an attempt was made to identify where such technology could be retrofitted to currently practiced processes.

This report was submitted in partial fulfillment of Contract 68-03-2198 by Arthur D. Little, Inc. under sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 9, 1975 to May 14, 1976.

II. SCOPE

During the first month of work under this contract, a priority ranking of 25 industry sectors was established. It was largely based on judgment of selected senior ADL staff members; the ranking was then supplemented by readily available energy consumption data as detailed in the Industry Priority Report (Vol. II). The scope of this study includes the following 13 industry sectors which were identified as having the primary opportunities for energy conservation through new technology or modifications to existing process technology.

- Primary Metals Industry (SIC 33)
 - Blast furnaces and steel mills
 - Alumina and primary aluminum
 - Primary copper
- Petroleum and Coal Products (SIC 29)
 - Petroleum refining
- Chemical and Allied Products (SIC 28)
 - Olefins
 - Ammonia
 - Fertilizers
 - Alkalies and chlorine
 - Phosphorus and phosphoric acid
- Paper and Allied Products (SIC 26)
- Stone, Clay and Glass Products (SIC 32)
 - Cement
 - Glass
- Textile Mill Products (SIC 22)

Annual energy consumption for these 13 industry sectors, shown in Table 3, amounts to about 12 quads,* accounting for about 60 to 65% of the energy purchased in the manufacturing sector.

Several hundred processes and process options were screened in this study with over 100 being at least discussed qualitatively in these reports. Table 4 shows the 80 processes or process steps which were included for detailed analyses. Fifty-five of these represent new technological process options, while the remaining 25 represent "base line or current processes" against which environmental/energy/cost impacts were gauged.

In selecting changes to be included in this study, criteria were established as delineated in the Industry Priority Report. For example, energy conservation is defined broadly to include conservation of form value of energy by a process change, e.g., conserving natural gas even while using more energy units of coal, or a feedstock change. Moreover, energy conservation resulting from changes in either industrial practice or pollution control methods is included within the scope of this study. Emphasis was placed on process changes with near-term rather than longer term potential within an approximate span of the next 15 years to 1990. Because of work funded under other Government contracts** and the desire to focus this study on process changes, the following were not considered to be within the scope of this present study:

- Improved waste heat utilization;
- Energy conservation as a result of better maintenance or "house-keeping" (e.g., shutting off standby furnaces);
- Power generation;
- Steam generation by alternative fuels (e.g., use of coal for oil or gas, carbon monoxide boilers);
- Fuel substitution in fired process heaters;
- Mining and milling, animal husbandry, agriculture;
- Substitution of scrap such as iron, aluminum, or glass, and materials based on virgin materials, except for the de-inking of waste paper which has some unusual environmental problems with energy implications;

*quad = 10^{15} Btu

**A compilation of research in the energy field being conducted by the U.S. Government, industry, universities, and foreign institutions is contained in "Energy Conservation Research and Development," Vol. 2. Nov. 21, 1975, ICF Incorporated, Wash. D.C. This report was sponsored by EPA under Contract 68-01-3414, BOA 68-01-2472, Task 2.

TABLE 3

SUMMARY OF 1971 ENERGY PURCHASED IN SELECTED INDUSTRY SECTORS

<u>Industry Sector</u>	<u>10¹⁵ Btu/Yr</u>	<u>SIC Code In Which Industry Found</u>
1. Blast furnaces and steel mills	3.49 ⁽¹⁾	3312
2. Petroleum refining	2.96 ⁽²⁾	2911
3. Paper and allied products	1.59	26
4. Olefins	0.984 ⁽³⁾	2818
5. Ammonia	0.63 ⁽⁴⁾	287
6. Aluminum	0.59	3334
7. Textiles	0.54	22
8. Cement	0.52	3241
9. Glass	0.31	3211, 3221, 3229
10. Alkalies and chlorine	0.24	2812
11. Phosphorus and phosphoric acid production	0.12 ⁽⁵⁾	2819
12. Primary copper	0.081	3331
13. Fertilizers (excluding ammonia)	0.078	287

(1) Estimate for 1967 reported by FEA Project Independence Blueprint, p. 6-2, USGPO, November 1974.

(2) Includes captive consumption of energy from process byproducts (FEA Project Independence Blueprint)

(3) Olefins only, includes energy of feedstocks: ADL estimates

(4) Ammonia feedstock energy included: ADL estimates

(5) ADL estimates

Source: 1972 Census of Manufactures, FEA Project Independence Blueprint, USGPO, November 1974, and ADL estimates.

TABLE 4
PROCESSES SELECTED FOR DETAILED ANALYSIS

Industry Sector	Process Selected	Baseline Process	Product
Alumina and primary aluminum	Nitric acid leaching process	Bayer	Alumina
	Hydrochloric acid leaching process	Bayer	Alumina
	Toth alumina process	Bayer	Alumina
	Alcoa chloride electrolysis process	Hall-Heroult	Aluminum
	Application of titanium diboride cathodes to the existing Hall-Heroult cells	Hall-Heroult	Aluminum
Ammonia	Toth Alumina with Alcoa Chloride process	Bayer with Hall Heroult	Ammonia
	Ammonia via coil gasification	Ammonia via natural gas	Ammonia
	Ammonia via heavy oil gasification	Ammonia via natural gas	Ammonia
Cement	Flash calciner	Natural gas or oil fired long kiln	Portland cement
	Fluid-bed cement process	Natural gas or oil fired long kiln	Portland cement
	Suspension preheater	Natural gas or oil fired long kiln	Portland cement
Chloralkali	Conversion to coal from oil & natural gas (a)	Natural gas or oil fired long kiln	Chlorine-caustic soda
	Dimensionally stable anodes-conventional	Graphite anode diaphragm cell	Chlorine-caustic soda
	Dimensionally stable anodes-expandable	Graphite anode diaphragm cell	Chlorine-caustic soda
Fertilizers	Dimensionally stable anodes-polymer membrane	Graphite anode diaphragm cell	Chlorine-caustic soda
	Dimensionally stable anodes-ion exchange membrane	Graphite anode diaphragm cell	Chlorine-caustic soda
	Modern mercury cell	Graphite anode diaphragm cell	Chlorine-caustic soda
Glass	Nitric acid with catalytic reduction for NO _x	Nitric acid with no NO _x abatement	Nitric acid
	Nitric acid with molecular sieve for NO _x	Nitric acid with no NO _x abatement	Nitric acid
	Nitric acid with Grande Paroisse for NO _x	Nitric acid with no NO _x abatement	Nitric acid
Iron and steel	Nitric acid with CDL/Vitok for NO _x	Nitric acid with no NO _x abatement	Nitric acid
	Nitric acid with Waser for NO _x	Nitric acid with no NO _x abatement	Nitric acid
	Fuel oil firing of fertilizer dryers where emissions are controlled by bag filters	Natural gas fired dryers	Mixed fertilizers
Olefins	Coal gasification & glassmaking	Natural gas fired furnace with cold charge (b)	Glass (soda-lime)
	Direct coal firing	Natural gas fired furnace with cold charge (b)	Glass (soda-lime)
	Electric melting	Natural gas fired furnace with cold charge (b)	Glass (soda-lime)
Fertilizers	Coal, hot gas generation & glassmaking	Natural gas fired furnace with cold charge (b)	Glass (soda-lime)
	Batch preheating & glassmaking	Natural gas fired furnace with cold charge (b)	Glass (soda-lime)
	CO collection from BOP	Combustion of offgases	Steel
Iron and steel	Direct reduction-electric furnace	Coke oven, blast furnace, BOP	Steel
	External desulfurization of blast furnace hot metal	Desulfurization in blast furnace	Blast furnace hot metal
	Dry quenching of coke	Wet quenching	Quenched coke
Olefins	Naphtha coil cracking	Ethane-propane coil cracking	Ethylene
	Gas oil coil cracking	Ethane-propane coil cracking	Ethylene

TABLE 4
PROCESSES SELECTED FOR DETAILED ANALYSIS (Cont.)

Industry Sector	Process Selected	Baseline Process	Product
Paper and Allied Products	Alkaline-oxygen pulping Bapson effluent-free kraft process Delinking of waste news as a substitute for mechanical pulping Thermo-mechanical pulping (TMP)	Conventional kraft Refiner mechanical pulp (RMP) Refiner mechanical pulp (RMP)	Slush pulp Slush pulp Slush pulp Slush pulp
Petroleum Refining	Direct combustion of asphalt in heaters/boilers Asphalt conversion by hydrocracking (H-OIL) Asphalt conversion by flexicoking Internal power generation using asphalt Hydrogen generation by partial oxidation	Regional cluster model for 1985 product mix Regional cluster model for 1985 product mix Regional cluster model for 1985 product mix Regional cluster model for 1985 product mix	Refinery products Refinery products Refinery products Refinery products
Phosphorus	Chemical cleanup of wet-process phosphoric acid Solvent extraction process for wet-process phosphoric acid "Strong acid" systems for wet-process phosphoric acid via "strong acid" process	Electrothermal phosphoric acid Electrothermal phosphoric acid Conventional wet-process phosphoric acid	Detergent grade phosphoric acid Detergent grade phosphoric acid Detergent grade phosphoric acid
Primary Copper	Outokumpu flash smelting Noranda process Mitsubishi process Oxygen use in flash smelting Metal recovery from slags by flotation Arbiter process	Reverb./converter Reverb./converter Reverb./converter No oxygen use in flash smelting metal recovery in electric furnace Reverb./converter/electrolytic refining	Blister copper Blister copper Blister copper Blister copper Refined copper
Textile	Integrated knit fabric mill using advanced aqueous processing(c) Integrated knit fabric mill using solvent processing(c) Integrated woven fabric mill using advanced aqueous processing(d)	Knit fabric mill using current aqueous processing Knit fabric mill using current aqueous processing Woven fabric mill using current aqueous processing	Knit fabrics Knit fabrics Woven fabrics

- (a) Forms part of baseline technology
(b) Side port-regenerative furnace
(c) 100% polyester fiber
(d) 50/50 polyester cotton fiber mix

- Production of synthetic fuels and coal (low- and high-Btu gas, synthetic crude, synthetic fuel oil, etc.);
- All aspects of industry-related transportation (such as transportation of raw materials).

While the scope of this study is not meant to be an all-inclusive assessment of all potential processes within the 13 industry sectors, we believe it does represent a realistic mix of alternative new processes likely to be considered in new plants for implementation by industry and, if implemented, having energy/environmental impacts.

III. APPROACH

The methodology used for analysis of the 80 processes identified for in-depth evaluation within the 13 industry sectors is outlined in the Industry Priority Report. Important aspects of the methodology include:

- Establishing a base line technology against which the process changes could be assessed. Normally this base line technology was currently practiced technology used in a major portion of the industry to make a given product. In choosing the base line and alternative processes, a deliberate attempt was made to start with the same or similar raw materials and produce the same or similar end-products.
- Determining the character and quantity of the pollutants emitted from the base line and alternative technology. Air, water, and solid waste were included in this assessment.
- Determining the energy requirements and the form of the fuel used in the base line technology. This included establishing whether oil, gas, or coal was needed as fossil fuel, for example. The different forms of energy were converted to a Btu basis, using common factors to the extent possible, as discussed in the Priority Report.
- Determining the investments and operating costs (both variable and fixed costs as well as a pretax return on investment) for pollution control and the basic processing operation.

In choosing base line and alternative technology, no attempt was made to determine the market acceptability of a product, such as an offcolor paper that might otherwise meet market requirements. However, when product quality might become an issue, it was pointed out in our discussion of the alternative process.

To establish uniformity in the costing methodology, we settled on the first half of 1975 as the basis for estimating capital investments in operating costs. Common unit energy costs by geographical region, as shown in Table 5, were used in this study. Again, where better information on the cost of various forms of energy was obtained from industry sources, we used the industry information and so identified it. In addition, labor rates by SIC classification were used as benchmarks within the industry assessment reports. Where such labor rates were close to those found in the Bureau of Labor Statistics information, we normally rounded off the hourly labor rates. In other cases where a particular industry segment had different labor costs, as determined from our industry contacts, the industry figures were used and so identified.

TABLE 5

BENCHMARK ENERGY COSTS FOR COAL, OIL, GAS, AND ELECTRIC POWER (MARCH 1975)

State	Fuel Prices* (¢/10 ⁶ Btu)			Estimated ** Power Costs (mil/kWh)
	Coal	Oil	Gas	
Arizona - Phoenix	69.7	195.9	61.4	20.6
California - Los Angeles	-	241.0	80.4	21.1
Florida - Tampa	97.7	188.7	71.3	21.5
Georgia - Savannah	82.4	184.2	77.3	18.8
Illinois - Chicago	70.8	154.5	84.6	19.2
Indiana - Indianapolis	58.4	201.1	101.5	16.7
Kentucky - Louisville	65.7	195.0	55.1	12.2
Louisiana - Baton Rouge	-	172.6	58.9	14.5
New Mexico - Albuquerque	21.9	209.7	56.5	16.8
New York - Buffalo	119.9	201.0	80.1	24.8
North Carolina - Greensboro	106.3	217.1	141.6	17.9
Ohio - Cincinnati	100.2	223.9	119.7	17.0
Oregon - Portland	-	184.9	105.7	5.7
Pennsylvania - Pittsburgh	92.1	214.4	-	24.6
South Carolina - Charleston	119.7	118.2	74.5	16.5
Tennessee - Memphis	83.6	214.6	-	11.9
Texas - Houston	21.0	186.9	69.8	13.6
Utah - Salt Lake City	50.3	158.6	55.1	16.5
Virginia - Norfolk	120.3	183.1	56.0	21.3
Washington - Seattle	57.2	-	-	3.9
West Virginia - Charleston	82.8	222.6	-	17.8
Wyoming - Cheyenne	27.7	-	-	12.5

*Average fuel prices paid by steam-electric plants, statewide.

**1974 average statewide industrial power costs multiplied by 1.17 which is the electric power price index ratio of March 1975 to 1974 average (DOC).

Source: Chemical Week, October 22, 1975.

We believe that the benchmark oil prices used in this study, which are in the nature of \$2/10⁶ Btu, are a reasonable reflection of the cost in 1975 of energy for new facilities. However, the gas and electric power industries are largely regulated, and we believe that many times the prices for gas and oil are not an accurate reflection of their value in the market. If deregulated, we would expect that the price of natural gas would be very close to that of oil. Making judgments about the future cost of electric power in 1975 dollars is a bit more difficult, however, because of the interplay between fossil fuel-based utility stations (oil, gas, or coal); the cost of pollution control equipment, if burning a high-sulfur fuel; the advent of nuclear power; and other reasons. Both investments in power plants, whether nuclear or thermal, and energy costs have risen dramatically in the past few years, and thus one can expect substantially higher power costs in the future. The availability and cost of such power can have an important influence on the future choice of alternative technologies and should be borne in mind when examining the cost tables presented for each one of the process options that we have analyzed. However, the tables will allow readers to make any corrective changes desired based on their own estimates of future energy costs.

The Industry Priority Report (Vol. II) describes in further detail the cost categories and methodology used in allocating investments and fixed costs, as well as the methodology used in establishing the pollution control technology, along with investments and operating costs.

IV. FINDINGS

Industries using large quantities of energy tend to be mature, enjoying relatively long plant lives in which rates of equipment renewal are low. Moreover, these industries are generally capital-intensive and changes are implemented gradually, resulting in considerable time spans before a significant portion of industry capacity is affected by any process changes.

If not in commercial operation abroad, the process changes considered in these reports have mostly been piloted - at least on a fairly large scale - and thus are seriously being considered by industry. Our findings on environmental/energy impacts of such new technologies are discussed below under two main topic headings:

- Pollution Control, and
- New Process Technology.

A. POLLUTION CONTROL

1. Overview

Using current environmental regulations as a guide, an examination of the new process technologies which might be installed indicates that there is little likelihood that the nature of the pollution control problems would be significantly altered from those now facing each of the industries studied. Clearly, the geographical location, mix of pollutants and volumes of particular wastes may well change (e.g., CaSO_4 generation and disposal from stack gas scrubbing). In some instances there is clearly a lack of technology to cope with the removal of fine particulates, such as metallic smokes from air streams; however, the most frequent reason for industrial resistance to the installation of pollution control equipment is based either on the costs or the lack of long-term demonstrated performance capabilities. Although the pollution control problems of the new processes will undoubtedly be considerably ameliorated by greater attention to the design and operation of the processes, all of the processes will produce air and water streams which must be emitted to the environment. Consequently, pollution control technologies for application at the end-of-the-pipe will still be of importance.

Undoubtedly there will be increased recycle of treated wastewater within industrial plants, a situation rarely achievable with gaseous streams, except perhaps in an installation such as dry quenching of coke. Nevertheless, system designs relying on large amounts of recycle are not achieved without penalties, such as the possible deterioration of product quality, or increased production of solid wastes, such as sludges, which must be disposed of in an environmentally acceptable manner. Consequently, research and development

efforts on pollution control technologies must be focussed not only on technology, but also researchers must be continually cognizant of their effects on the economy, while keeping in perspective the probable cost/benefits to the ecosystem. As Dr. Peter Lederman* has said (Industrial Water Engineering - February/March 1976), "The constraints are severe and fly in the face of the Third Law of Thermodynamics in that we are, during the manufacturing, adding entropy to the system which we now wish to remove at minimum energy cost. This is analogous to going uphill while expending no more energy than to go downhill. While we cannot realistically do this, we need to accept the challenge to approach it." In accepting this challenge, both industry and government must critically evaluate not only the technological objectives of research and development of pollution control systems, but must also carefully assess the results of these efforts in line with a cost/benefit analysis. As Dr. Barry Commoner** has pointed out: (1) everything is connected to everything else, and (2) there is no such thing as a "free lunch."

2. Pollution Control of Industrial Processes

Thus, in general, as a result of this study we have found:

- There are only a few new processes for which pollution control energy usage will be significantly different from present processes.
- The energy and capital requirements for controlling pollution to presently established levels usually do not represent a large portion of total production costs. The problem is usually the availability of capital and the costs incurred in a non-productive (pollution control) system.
- In going from gas to oil to coal, increased environmental impact in both obtaining the fuel and in using it can be expected.
- There is a relatively small amount of statistically significant data on the amounts of pollutants emitted from present manufacturing processes. At best, estimates of emissions from new processes can only be qualitative.
- Pollution control research and development (R&D) monies from private sources will always continue to be minimal, because operating companies rarely see an opportunity for a profit, and equipment manufacturers have not traditionally expended significant funds for research and development on pollution control equipment. Thus the bulk of R&D program support in such areas is dependent on Government agencies.

*At the time this report was prepared, Dr. Lederman was on the EPA Headquarters staff and was actively advising the Project Officer on this study.

**Dr. Barry Commoner, Closing Circle, published by Knopf, 1971.

- Research in pollution control technology over the past decade has resulted in improved efficiency of operation, but no startling breakthroughs in technology. In the large majority of cases, pollution control technology is known and the major problem is the demonstration of more efficient operating systems at reduced capital and operating costs.

Areas in which the EPA might fund research and development efforts within the 13 industry categories studied in these reports are expected to be largely in the technologies either for removal of pollutants from air and water streams, or for preventing the widespread environmental dispersion of concentrated pollutants emanating from the process operation. It became apparent that increased attention must be given to multimedia (air, water, land) effects and to the total environmental impact, e.g., determining whether the increased electrical energy used for particulate removal at an industrial plant results in more emissions (or more tolerable emissions) at the steam-generating plant. As the effectiveness of pollution control technologies improves, it will become more difficult to make further improvements technically or economically. Consequently, establishing emission limits which are consonant with the capabilities of the ecosystem to tolerate these emissions will become of increasing importance. This type of information is needed especially for gaseous pollutants such as (1) SO_x , NO_x , etc.; (2) organic compounds that may have high smog-forming characteristics, long biological half-lives, or carcinogenic potential, and (3) fine particulates, especially metallic smokes. Of course, the organic compounds mentioned above are of equal interest in water pollution control where, in addition, the removal of dissolved metals and suspended solids are other areas of major concern.

In both the air and water pollution control field, there is a need for improved instrumentation for rapid monitoring and recording of the pollutants of concern. Increasing problems in the field of solid wastes require not only demonstration of control technologies, but also establishing the categorization, and legal methodologies to be utilized in regulating this waste problem. Areas where research and development efforts should be concentrated and a ranking of the relative importance within an industry sector are further discussed below.

a. Air Pollution Control Technology

With regard to air emissions in the new technology investigated, we have identified the following to be deserving of R&D attention:

- Improving fine particulate removal technology. This would include especially those particulates resulting from metallic smokes and sublimed substances such as mercury, arsenic, zinc, etc. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, ammonia, cement, copper, fertilizer, glass, iron and steel, petroleum refining, phosphorus, and pulp and paper.
- Collection or control of fugitive emissions from process equipment. Further information on the source of pollutants and nature of the

problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, ammonia, copper, fertilizers, iron and steel, and textiles.

To a lesser extent, it is also a problem in the following industry sectors: cement, olefins, petroleum refining, phosphorus, and pulp and paper.

- Better definition of the environmental, health, and ecological impacts of gaseous emissions (such as SO_x , NO_x , CO, HF, Cl_2 , NH_3) with respect to obtaining more quantitative knowledge for establishing appropriate emission regulations. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, ammonia, cement, chlor-alkali, copper, glass, iron and steel, petroleum refining, and pulp and paper.

To a lesser extent, it is also a problem in the olefins industry.

- Better definition of the environmental, health, and ecological impacts of metallic smoke emissions with respect to obtaining more quantitative knowledge for the purpose of establishing appropriate emission regulations. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, ammonia, cement, copper, glass and iron and steel.

To a lesser extent, it is also a problem in the olefins and petroleum refining industry sectors.

- Better definition of the environmental, ecological, and health impacts of organic compounds that have a high smog characteristic or potential carcinogenic properties. More quantitative knowledge is needed for the purpose of establishing appropriate emission regulations. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, iron and steel, olefins, petroleum refining, and textiles.

To a lesser extent, it is also a problem in the pulp and paper industry.

- Improvements in odor control. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with petroleum refining and pulp and paper.

To a lesser extent, it is also a problem in the olefins industry.

- Improved instrumentation for rapid monitoring and recording of airborne emissions. Further information on the source of pollutants and nature of the problems in new technology examined in this study

is found in the Industry Assessment Reports dealing with aluminum, copper, glass, iron and steel, and pulp and paper.

To a lesser extent, it is also a problem in the following industry sectors: cement and petroleum refining.

b. Water Pollution Control Technology

With regard to water pollution control in new technology investigated in this study, we have identified the following as deserving consideration for additional research and development.

- Better definition of the environmental, health, and ecological impact of substances which cannot be removed by Best Available Technology Economically Achievable (BATEA). This will include principally metals and organic compounds that have long biological half-lives or carcinogenic effects. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, ammonia, copper, iron and steel, petroleum refining, phosphorus, and pulp and paper.
- Improvements in suspended solids removal from treated wastewaters. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with ammonia, iron and steel, petroleum refining, phosphorus, and pulp and paper.

To a lesser extent, it is also a problem in the aluminum, cement, chlor-alkali, and copper industry sectors.

- Removal of refractory organic compounds not achievable by technologies now designated by EPA as BATEA. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with iron and steel and textiles.

To a lesser extent, it is also a problem in the aluminum industry.

- Improvements in color removal. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with pulp and paper, and textiles.

To a lesser extent, it is also a problem in the petroleum refining industry.

- Removal of dissolved metals or inorganic salts. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, iron and steel, and phosphorus.

To a lesser extent, it is also a problem in the chlor-alkali, copper, glass, and petroleum refining industry sectors.

- Improved instrumentation for rapid monitoring and recovery of water-borne pollutants. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with iron and steel, and pulp and paper.

To a lesser extent, it is also a problem in the ammonia, olefin, phosphorus, and textile industry sectors.

c. Solid Waste Disposal

With regard to solid wastes emanating from new technology investigated in this study, the following have been identified as deserving R&D attention.

- Demonstration of adequate landfill disposal techniques. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, cement, iron and steel, petroleum refining, and phosphorus.

To a lesser extent, it is also a problem in the ammonia, chlor-alkali, copper, glass, olefins, pulp and paper, and textile industry sectors.

- Demonstration of thermal destruction technologies. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment reports dealing with aluminum, olefins, and petroleum.

To a lesser extent, it is also a problem in the chlor-alkali, iron and steel, and pulp and paper industry sectors.

- Additional research into the methods of categorization, regulation and legal methodologies for controlling the disposal of solid wastes. Further information on the source of pollutants and nature of the problems in new technology examined in this study is found in the Industry Assessment Reports dealing with aluminum, ammonia, cement, copper, fertilizers, glass, iron and steel, olefins, petroleum refining, and phosphorus.

To a lesser extent, it is also a problem in the chlor-alkali, pulp and paper, and textile industry sectors.

Thus, in each case, the direction of research programs should be viewed with the objective of attaining the maximum effectiveness for removal or controlling pollutants at the minimum economic penalty, since it is rarely possible to remove or control pollutants to present and anticipated standards without entailing cost penalties. Consequently, research programs must be examined within the framework of cost/benefits to the environment, to health, and to the economy.

B. NEW PROCESS TECHNOLOGY

In presenting our findings, we recognize that the quality of the reported estimates is highly variable; it is influenced by the development stage of the emerging technology, and hence the amount and type of laboratory data and operating experience that have been accumulated. The stage of commercialization is an implicit indication of the quality of the reported data and is reported in the Industry Assessment Reports (Volumes III-XV), along with the details of the process evaluation. Thus, conclusions should not be derived from the findings summarized here without at least a careful reading of the appropriate Industry Assessment Reports.

Within the processes considered in this study, the major findings are:

- Coal is being considered as an alternative fuel or feedstock in many industries, including ammonia, cement, copper, glass, and iron and steel (steam coal for metallurgical coal). Thus, pollution problems associated with the use of coal can be expected to increase.
- Pollution control legislation is forcing industry to consider new process technologies, many of which are energy-conserving. Examples are found in copper (flash smelting, Mitsubishi, and Noranda processes), nitric acid plants (NO_x abatement using newer technology), pulp and paper (Rapson process^x), and textiles.
- Preheating is being considered in many industry sectors. Examples are found in the glassmaking and cement industries.
- Relative energy costs (e.g., cost of natural gas vs. oil vs. coal) can affect the relative economics of process options rather significantly in some industry sectors. Examples can be found in the ammonia and glassmaking industries.
- Changes in raw materials or feedstock availability are causing many new processes to be examined. Examples are found in alumina (clay leaching process), ammonia, olefins, and petroleum refining.
- High-cost electric power and its availability are prompting the examination of newer technology. Examples are found in chlor-alkali production (new cell technology), phosphoric acid (cleanup of wet-process acid to meet furnace-acid specifications), and aluminum (Alcoa process).
- From a technical viewpoint, energy can be recovered using new process technology, such as carbon monoxide collection from basic oxygen furnaces in steelmaking and in the dry quenching of coke. However, some of these technologies, such as dry quenching, do not appear to be economically viable in the United States at present day energy costs.

The alternative technologies considered and base line processes are shown in Table 4, along with products produced. Further details are contained below with findings in each of the industry sectors presented in alphabetical order.

1. Alumina and Aluminum

a. Alumina

(1) Solid Waste

It is clear that more solid waste will be produced from treating clays to recover alumina by any of the new processes--namely, nitric acid or hydrochloric acid leaching or the Toth chlorination process-- than is produced by the existing Bayer alumina process. This is because bauxite used in the Bayer process contains about 50% alumina, while clay typically contains only 30-35% alumina so that there is simply more inert material. However, with the processing plant near the clay mines, the waste could be returned to mined-out areas, whereas in the case of a Bayer alumina plant the bauxite is imported and space must be found to dispose of the solid wastes ("red mud") from the Bayer plants. (Of course, additional solid waste is generated where bauxite is mined.)

(2) Liquid Waste

In the case of the nitric acid leaching process, the liquid wastes will contain soluble nitrates, along with other tramp elements, whereas with the hydrochloric acid and Toth chlorination processes the wastes will contain soluble chlorides. The latter are generally less objectionable than soluble nitrates. If complete impoundment in an impervious, barrier-lined disposal area ("zero discharge") were utilized, the pollution control costs would be greater for any of the clay-based processes than for the present Bayer alumina plants.

(3) Gaseous Emissions

The gaseous emissions from the existing Bayer alumina plants are minor, limited largely to emissions from the boiler house; these are SO₂, in amounts depending on the fuel used, and dust from alumina and lime calcination, all of which can be controlled to a level meeting existing or anticipated regulations.

In the case of the nitric acid and hydrochloric acid leaching processes, the tail gases from the decomposition-acid recovery operation could be removed by caustic scrubbing, but would result in water soluble nitrates and chlorides. Removal of these dissolved inorganic salts would be costly and, in some removal systems, energy-intensive. Existing or anticipated effluent limitations for biologically non-nutritive inorganic salts would not preclude their emission. However, the nutritive nitrate salts from the nitric acid process will probably require more extensive control than might be required from the hydrochloric acid, Toth chlorination, and Bayer alumina processes.

(4) Costs

In the Bayer process, the cost of pollution control at \$1.40/ton of alumina is minor, considering the present value of alumina at \$125/ton. The cost for complete environment control of the new nitric acid and Toth clay-based processes is estimated to be significantly higher (\$4 to \$20/ton alumina), which compares with total estimated production costs of over \$200/ton alumina.

(5) Energy

Energy consumption for alumina production based on clay is least for the Toth chlorination, followed by the acid leaching processes. However, all are higher than the on-site usage for production of alumina from bauxite which does not include the energy consumption for mining the bauxite or transportation to the United States.

b. Aluminum

(1) Air Pollution

It seems that the Alcoa process and the use of titanium diboride cathodes will reduce air pollution problems from the cells and from the anode-making/baking operations. In the case of the Alcoa chloride process, the anodes will be inert; this means that anodes would be purchased rather than produced at the plant, so that air pollution from anode-making in the Alcoa process would be completely eliminated from the aluminum plant. In the case of the use of titanium diboride cathodes, the fluoride emissions per ton of aluminum produced would remain the same, but the gas volume to be scrubbed would be lower. Moreover, we would expect less carbon monoxide emissions per ton of aluminum produced.

It appears that costs for air pollution control from the cells and cell rooms of the new Alcoa process and for the use of titanium diboride cathodes in the Hall process would be less than the costs of producing aluminum in the existing Hall-Heroult cells. The Alcoa process would be completely closed to recover chlorine for reuse and, while there might be some losses of chlorine and/or HCl to the atmosphere, these would not be as serious as fluoride emissions. However, the Alcoa process would add a new source of gaseous emissions, namely, sulfur from the coking step and hydrogen chloride from the chlorinator tail gas. Of course, both can be removed as required.

(2) Liquid and Solid Waste

The use of titanium diboride would not significantly change the liquid waste problem from that of the present operations. However, the new Alcoa process may introduce a new source of liquid and solid waste, which would consist of sludge and sodium chloride from the cells to bleed off impurities from the electrolyte.

(3) Costs

The estimated cost of complete environmental control of aluminum plants is a significant factor in both the capital and operating costs of aluminum smelters, amounting to 6% of the cost of aluminum from present day plants, using prebaked electrodes. We are not suggesting reducing standards, but we believe that the requirements could be reviewed and possibilities for improving the pollution control systems should be considered. On the other hand, the new Alcoa process offers a substantial reduction in pollution control costs, largely because of the elimination of the use of fluoride compounds. Total production costs are estimated to be 5% lower for the Alcoa chloride process.

(4) Energy

Total energy consumption for production of aluminum via use of titanium diboride or the Alcoa chloride process can be expected to be 10-20% less than in conventional Hall-Heroult cells.

2. Ammonia

a. Ammonia from Coal

The problems associated with coal gasification are usually gaseous sulfur, non-methane hydrocarbons formed in the gasifier, wastewater, ash and slag. In making ammonia from gasified coal, the sulfur must be removed for process reasons and, once removed, it requires a relatively minor addition of a sulfur-recovery plant to handle the environmental factors.

The methane and any traces of higher hydrocarbons, which do not take part in the synthesis, are removed from the ammonia loop in a purge stream which is used as supplemental fuel.

The wastewater volume is less in making ammonia feedstock than in other coal gasification processes, because the water is recycled to the reactor to provide steam. The components of the ash and slag are similar to those produced in normal industrial coal-fired boilers.

There will be few problems for commercial ammonia plants based on coal feedstock in meeting the anticipated environmental standards. Difficulties will be no greater than those encountered in electric power generation, or in industrial coal-fired boilers and attributable to coal.

In certain geographical areas, use of strip-mined coal is attractive for this process alternative, since it provides a lower cost feedstock and a potential place in which to dispose of the large quantities of ash and slag. State and EPA regulatory policy in developing groundrules related to strip mining can affect costs and influence the trend of the ammonia industry in choosing feedstock and slag-disposal methods.

b. Ammonia from Heavy Fuel Oil Alternative

As in the coal alternative, the significant potential environmental problem is associated with sulfur. The sulfur must be removed for process reasons and is controlled by the addition of a sulfur recovery plant. The process wastewater is treatable in conventional biological treatment plants. Therefore, there will be no unique problems for commercial ammonia plants based on oil feedstock in meeting the anticipated environmental standards.

3. Cement

Our findings indicate that the quantities and compositions of the various effluent and process streams associated with the alternative processes considered in this study are essentially the same as those associated with the

conventional long rotary kiln. In all cases, a hydrocarbon fuel is burned with air to generate the heat required for the cement clinker production. The combustion gases carry dust and volatilized elements from the reactor (i.e., rotary kiln or fluidized bed). The percent excess air, chemical composition, and particle distribution of the particulates will change, but it appears that there are no new species of pollutants and no new effluent streams created. Nitrogen oxide concentrations may well be lower with the flash calciner and fluid bed process. In addition, the fluid bed process claims to have a smaller amount of particulate emissions with higher amount of potentially valuable alkali sulfates in the collected particulates.

The changes in both cement industry practice and process technology which we have studied will not result in any potential conflict with anticipated environmental regulation. For all alternative processes examined, energy use for pollution control is under 0.1×10^6 Btu/ton cement with process energy requirements being about 3 to 6×10^6 Btu/ton cement. Costs of environmental control are about \$1.90 $\pm$ \$.50 for all alternatives, or about 4% of calculated operating costs in a new plant. Significant environmental aspects of the industry practice and process changes studied are summarized below.

a. Suspension Preheater

The suspension preheater-equipped rotary kiln is a well-developed, established cement clinker production step outside the United States. Although it gained rapid acceptance in the United States in the 1950's, this clinkering alternative fell into total disfavor with the U.S. cement industry due to operating and cement quality problems. However, the present high fuel costs, combined with continued and apparently successful development and operation of the suspension preheater outside the United States, has led to its recent reexamination. Because of extensive experience with actual commercial-scale operations in a large number of plants throughout the world, the environmental aspects of the suspension preheater-equipped rotary cement kiln are quite well known.

Suspension preheater-equipped cement plants are dry process plants, and therefore have no process water discharge. Typically, suspension preheater-equipped plants operate with a total dust return to the clinkering step, and therefore have no waste kiln dust-disposal problem. Occasionally, to meet alkali specification in the finished cement, preheater kilns are operated with a bypass of some of the kiln exit gases. The dust collected from this bypass is discarded, since it is high in alkali content and thereby provides an alkali purge stream from the process. The quantities of particulates and SO_2 from a suspension preheater kiln are well known and present no problems in either magnitude or nature different from those with which the cement industry is presently familiar.

If waste kiln dust from a suspension preheater bypass system is discarded, its physico-chemical characteristics are similar to kiln dusts from cement plants operating in the United States today. Therefore, the rainwater run-off and leaching problems associated with the disposal of waste kiln dust from such a system should also be no different from those associated with the disposal of kiln dust from plants operating today.

b. Flash Calciner

This is a significant new variation of the suspension preheater rotary kiln which has gained wide acceptance in Japan and Europe. The first commercial installation in the United States is presently nearing completion. Since the flash calciner is a dry process, the same observations and comments made on the suspension preheater apply. Approximately 50% of the total fuel required for the clinker production step is burned at a relatively low temperature, with a low percent excess combustion air and quite uniform combustion gas composition throughout the combustion chamber. It has been reported that these characteristics are responsible for the NO_x produced by a flash calciner-equipped kiln being significantly lower than for either the suspension preheater or long rotary kiln.

The particulates and SO_2 emissions from the flash calciner-equipped rotary kiln are expected to be approximately the same as those from a suspension preheater, except when part or all of the rotary kiln combustion gas bypasses the flash calciner and suspension preheater vessels in order to produce low alkali cement. Although no data are presently available on the efficiency of SO_2 collection within the rotary kiln by chemical reaction with the calcined cement, it is expected to be quite high. However, there remains the possibility that the SO_2 emissions from a partial or total bypass system may be in conflict with air pollution regulations.

c. Fluidized-Bed Cement Process

The fluidized-bed cement process utilizes a fluidized-bed reactor, rather than a rotary kiln, for the production of portland cement clinker. Although no commercial plant has yet been built using the fluidized-bed clinkering reactor, a semi-commercial-scale plant of 100-ton/yr capacity was built and operated successfully for a period of several years.

The data reported indicate that the combustion gases leaving the fluidized-bed reactor are as low in SO_2 as those of a rotary kiln and also significantly lower in particulates. The fluidized-bed cement process is a dry process, and therefore has none of the process water effluent which is common to the conventional wet-process plant.

This process, offered to the cement industry by two U.S. firms, employs the generation of steam as one mode of process heat recovery, and is reported to be equivalent in overall thermal efficiency to the suspension preheater-equipped rotary kiln which uses about 4.2×10^6 Btu/ton cement compared to about 6×10^6 /ton cement for the conventional long rotary kiln. Within the scope of this study, such energy usage represents the lowest consumption of Btu per ton of cement produced.

The fluidized-bed clinkering reactor will produce cement clinker of significantly lower alkali concentration than any of the rotary kiln-type clinkering processes, all other things, such as the chemical and physical characteristics of the raw material, being constant. This results from the significantly higher extent of alkali volatilization in the fluidized-bed reactor and the

indirect means of heat recuperation from the hot combustion gases exiting the reactor. In the rotary-kiln types of clinkering process alternatives, heat recuperation is by direct contact of air with raw material particles.

Therefore, the majority of the particulates contained in the combustion gases leaving the fluidized-bed reactor are quite different from those from any of the rotary kiln-type processes. Approximately 97% are water-soluble potassium and sodium sulfate, and the remaining 3% are finished clinker particles. Also, since the extent of alkali volatilization in the fluidized-bed process is significantly greater than in the rotary kiln-type clinkering process, the quantity of alkali sulfate emitted in the effluent combustion gas stream discharged will be significantly higher--maybe by a factor of 2 or 3--than in a comparable rotary kiln-type clinkering process. Since most of these particulates are alkali sulfates which have been volatilized from the clinkering raw materials, they are expected to be extremely fine and are more appropriately defined as a fume. Glass cloth filters should serve to suitably collect these particulates. Although no specific data are reported concerning the operation of such a collection device, the total pounds of particulates emitted per ton of cement clinker produced are expected to be considerably less than from any of the rotary kiln-type clinkering processes. This should result in a significant economic benefit of this process in the discarding or disposal of the particulates, especially if these alkali sulfates have a value as a chemical raw material or plant nutrient, for example.

Actual data obtained from the operation of a pilot-scale, fluidized-bed cement reactor show that the NO_x concentration in the combustion gases is significantly less than from an equivalent rotary-kiln process. The reasons for this are that the fluidized bed reactor operates at a lower temperature and the combustion of fuel in the fluidized-bed reactor can be carried out with only a very small quantity of excess air. Also the high heat and mass-transfer rates which are exhibited by fluidized beds reduce oxygen concentration gradients within the gas phase to very low levels.

d. Conversion to Coal from Natural Gas and Oil

Coal firing of long kilns can be considered part of the base line technology, since it accounts for some 40% of the portland cement production. With recent gas shortages and high oil prices, coal firing is expected to play a larger role in the future. Pulverized coal can be successfully burned as the fuel in any of the rotary kiln cement installations in the United States today. The two main environmental consequences of switching from natural gas or oil to coal are:

- Fugitive particulate emissions and rainwater run-off which come from the storage and handling of coal; and
- the presence of coal fly ash in kiln dust which is discarded.

Coal-fired steam electric generating facilities handle and store large quantities of coal today. The equipment and handling techniques used by these utilities should prove equally satisfactory for the control of fugitive emissions

which will attend the use of coal in cement plants. The presence of coal fly ash in the kiln dust will increase the number of elements, and possibly the concentration of presently existing elements, in the dust. However, this does not appear to be in potential conflict with any environmental regulations.

4. Chlor-alkali

During the next 15 years the following evolutionary changes in the industry are expected in approximately the order listed:

- Existing graphite anode plants will be converted to dimensionally stable anode (DSA) cells;
- Deposited asbestos diaphragms will be replaced by stabilized asbestos diaphragms.
- New plants will use combinations of expandable DSA-type cells, or wide DSA's with stabilized asbestos diaphragms;
- Microporous membranes will supersede the use of asbestos in new plants and probably be used for some existing plant modernizations;
- Mercury cells which expose the industry to considerable risk in the form of plant maloperation or accidents and which use more energy (combining both electrical and thermal forms) than the newest DSA-modified diaphragm cells will be slowly phased out over the next 10 years;
- Perfection of the ion-exchange membrane cell will enable it to replace economically mercury cells in existing mercury cell plants.

The effect of these changes will be a reduction of 15% or more in the average energy consumed by the industry per ton of product. Although the present environmental problems of the industry, with the exception of mercury cell plants, are comparatively minor, these changes will ease existing problems. The already small volume of chlorinated organic waste associated with the use of graphite anodes will be eliminated, as will the solid graphite waste from spent anodes. Traces of lead in wastewater arising from the lead used to set the graphite will also be eliminated. Stabilized asbestos diaphragms will greatly reduce solid asbestos waste from spent diaphragms and will essentially eliminate asbestos fibers in wastewater. Polymer membranes, either microporous or ion exchange, ultimately will eliminate all asbestos from the plant. Higher purity cell gas from DSA cells will reduce the amount of gas necessarily vented from the chlorine liquefaction system. In summary, none of these process changes in themselves is expected to create new environmental problems. On the contrary, the changes are expected to further reduce the amount of pollution by industry. In all cases the environmental costs are small and these changes will be evolutionary, based primarily on process economics.

5. Copper

a. Pyrometallurgical Processes

The new pyrometallurgical processes (Outokumpu, Noranda, and Mitsubishi) have two characteristics which make them more energy-efficient and less polluting compared to conventional reverberatory smelters:

- They utilize the heat of oxidation of sulfur and iron to supply a part of the process energy requirements; and
- They produce steady concentrated streams of SO₂ suitable for the manufacture of sulfuric acid.

The reduction in energy consumption is significant, amounting to about 30-50% (the latter when using oxygen enrichment). The processes are quite flexible in their ability to use any form of energy: gas, oil or coal. The reduction in SO₂ emissions is also significant. Compared to sulfur capture of 50-70% for conventional smelting, the new processes achieve a sulfur capture of more than 90%. Since only concentrated SO₂ streams are produced, the cost of controlling over 90% SO₂ in the new processes is about the same as that for 50-70% control for conventional smelting.

The forces which would make U.S. industry adopt this technology would be EPA regulations limiting SO₂ emissions and high-energy costs in the future. Other factors should also be considered, however. The U.S. copper industry has traditionally increased capacity by expanding and modifying existing smelters and refineries because of the large capital investment per dollar of revenue potential, relatively low growth in demand, cyclical nature of demand, and international trade in refined metal. In an inflationary economy the costs of production from existing, partially depreciated facilities would be much lower than production costs for new facilities. New source performance standards affecting the copper industry will constrain certain modes of capacity expansion at existing smelters.

The sulfuric acid produced would have to be utilized or means found for disposal. The typical western U.S. smelter locations are distant from major sulfuric acid markets, and the sulfuric acid has been utilized for leaching of marginal resources (mine dumps, tailings, oxide ores, etc.), or for making wet-process phosphoric acid. The leaching of dumps and surface deposits without contamination of groundwater is possible in the arid West, but might not be possible in other parts of the United States. As a last resort, neutralization with limestone or the reduction of concentrated SO₂ streams to elemental sulfur would have to be considered. These options would have their own impacts in terms of solid waste disposal.

The major shortcoming of the new processes is that their applicability to "impure" concentrates (concentrates high in As, Sb, Bi, Pb, Zn, Se, Te, etc.) is unproven. Until this issue is resolved, the new processes would be utilized for building large smelters to smelt "clean" concentrates in regions where acid markets are available and at a time when anticipated demand can no longer be fulfilled via expansion of existing smelters.

In spite of this, we believe that three or four new pyrometallurgical plants (Outokumpu, Noranda, etc.) will be built in the United States by 1985-1990.

b. Oxygen Use in Smelting

The use of oxygen in smelting decreases fuel requirements and is energy-efficient overall, because the decrease in fuel requirements is usually larger than the energy required for oxygen separation. The use of oxygen enrichment can increase capacities of existing units and decrease capital costs per unit of output from new facilities. Smaller benefits are the ability to melt more scrap and the production of more concentrated SO_2 streams suitable for economical recovery as H_2SO_4 in some cases. (Use of oxygen in place of air also largely eliminates any NO_x problems.) We believe that these advantages (and the absence of disadvantages other than higher operating temperatures and consequently increased maintenance) will lead to the widespread adoption of oxygen enrichment.

c. Recovery of Metals from Slag

The new pyrometallurgical processes are economically viable only if the metal contained in the slag from the primary smelting unit can be recovered. Thus, these processes (i.e., slag laundering) are important adjuncts to the new smelting processes and, in addition, might be used in existing smelters (e.g., treatment of converter slags via flotation). The processes can decrease flux requirements, improve smelting unit operations, and aid conservation by increasing the overall recovery of copper in some cases. Of the two processes, electric furnace cleaning entails somewhat lower cost, but the higher copper recovery in slag flotation compensates for its higher costs. The energy requirements are about equal for both processes.

Although slag flotation produces a finely ground slag which is different from the slag from conventional processing, this slag can be placed into land disposal areas which have been especially prepared to mitigate the possibility of long-term emissions to the environment. Although the particular handling method will be unique to the geological aspects of the area, it is not expected that slag disposal will present environmental problems significantly different from disposal of mine tailings.

d. Hydrometallurgy

(1) The Arbiter Process

We estimate that the Arbiter process would be significantly more expensive for treating chalcopyrite concentrates compared to conventional smelting and refining. We believe that this process will be used on other concentrates with favorable mineralogy, e.g., chalcocite concentrates, in locations distant from sulfuric acid markets and where a full-sized pyrometallurgical plant is risky because of the cyclical nature in copper demand.

The Arbiter process and hydrometallurgical processes in general are not energy-efficient and utilize the same or slightly more energy than conventional smelting and refining. The leached solid wastes will require land disposal into areas prepared so as to prevent groundwater leaching of soluble substances and

to prevent airborne particulates. Because the plant will be located generally in the semi-arid western United States, establishing such a disposal area can be carried out with a high degree of confidence so that the environmental impact would probably be no worse than with slag disposal from conventional pyrometallurgical operations.

6. Fertilizers

a. Nitric Acid

The manufacture of nitric acid generates significant emissions of nitrogen oxides to the atmosphere. The most widely used process for pollution control is the catalytic decomposition of these nitrogen oxides to nitrogen and oxygen. This process is energy-intensive and is particularly expensive for those nitric acid plants which cannot recover this energy in the form of usable steam. The problem is aggravated because natural gas is the required energy source. Most existing plants are limited by regulation on the quantities of gas they can purchase, and such natural gas is critical and non-substitutable for the manufacture of ammonia, which in most cases occurs at the same site. Natural gas use for pollution control reduces the amount available for other purposes, thus effectively reducing production. The natural gas requirement for pollution control of a 300-ton/day nitric acid plant is 232.6×10^9 Btu/yr. This amount could be used to produce 6,600 tons of ammonia, including process fuel requirements, or about 11,000 tons if used only for feedstock.

The catalytic reduction process produces steam which may be used elsewhere in the plant complex, and it may be argued that this reduces the energy input at some other point. Such an argument may not be valid for two reasons:

- Not all plants have use for the steam; and
- Such steam, if needed, could otherwise be provided with a fuel other than natural gas.

Other abatement systems are becoming available and hold the promise of lower investment and operating costs, significantly lower energy requirements, and no need for natural gas as the energy source. Also, since the catalyst reduction process is usually too expensive to operate in plants using low-pressure processes to manufacture nitric acid, two or three of these alternate processes allow more economical recovery for such plants. However, these other processes suffer from problems of maintenance of stringent operating conditions ("molecular sieve"), inapplicability to low-pressure nitric acid processes (Grand Paroisse), and too little actual experience (CDL/Vitok).

Costs for pollution control can be significant. The catalyst reduction process for controlling nitrogen oxide emissions would require a 25% addition in investment and an 11% increase in the total cost of manufacture.

The four alternative processes studied improve on these costs. The molecular sieve and Grande Paroisse processes entail investments on the order of \$1.2 and \$1.0 million, respectively, for a 300-ton/day nitric acid plant, and add \$4.01 and \$2.30/ton, respectively, to the cost of nitric acid. These figures are still significant but lower than those for the catalyst reduction process. Energy

requirements are also much lower in each of the four alternatives when compared to the catalyst reduction process. Not only is energy use lower in these other processes, but there is also no requirement for natural gas. Energy is consumed as electricity only in three of the options, and electricity and fuel oil in the molecular sieve option.

b. Fertilizer Mixing

In the drying of mixed granular fertilizers, considerable dust is generated. It has to be removed from the process air stream before venting to the atmosphere. In switching from natural gas to fuel oil for firing the fertilizer dryer, manufacturers have encountered operating difficulties with the bag filter. The problem arises from premature clogging of the filter for a variety of reasons, including incomplete combustion of the fuel oil, increased soot and ash formation, and, in the case of high-sulfur fuel oil, deposition of sulfate salts on the bag. To avoid these problems, some plants have switched to propane rather than to fuel oil. The scarcity and high price of propane make this an unlikely alternative to be considered in the future. Based on the results of our analysis and discussions with mixed fertilizer producers, we believe that it will be possible to upgrade burner equipment and operating procedures and to avoid the other two alternatives.

We estimate that only approximately 20% of the estimated 200 ammoniation-granulation plants being considered use bag filters to collect these dusts; the remainder use scrubbers. Thus, while the switch from natural gas to fuel oil will present problems to a few plants, the problem is not highly significant when viewed in an industry-wide context.

7. Glass

In the manufacture of glass products, the melting unit process is by far the most energy-intensive. Natural gas, because of its ease of handling, cleanliness, consistency and, until recently, its availability and low cost, is the primary energy form used to melt glass in the United States. Because of its scarcity and increased cost, alternative-fuel processes, principally coal-based, will be considered. All the coal-based alternatives considered here--viz., coal gasification, hot gas generation, and direct coal firing--greatly increase the emission loads from the glass furnace and, therefore, if used, will demand larger emission control systems. Additional solid-waste and water effluent streams also are involved in the separate processes of coal gasification and hot gas generation and require further pollution controls. Estimated cost of water pollution control (BATEA) ranges from \$7/ton of glass for a natural gas-fired furnace to \$9/ton with coal, using best available technology. However, one should note that at the present time, there are no proven technologies for the effective control of air emissions from a glass furnace fired with natural gas, nor any for the alternative fuel forms listed above. Effective scrubbing and filter systems have not yet been demonstrated.

Except for direct coal firing, the total energy consumption of these alternative glass melting unit processes using coal is about 25% greater than with natural gas. As a result of substantial investments and about a 30%

increase in operating costs, we find that processes such as coal gasification are not economically attractive alternatives to natural gas-fired furnaces at this time. Although economically attractive and energy-conserving, direct firing with coal is presently beset with serious technical problems which are related to the effect of the ash on glass furnace refractories and on glass quality; as such, its viability as an alternative is uncertain.

The electric melting process appears to be a technically and economically competitive alternative to gas-fired furnaces, although comparably sized furnaces have not yet been demonstrated. Air emissions from the glass furnace are substantially reduced in volume in electric melting, and therefore the cost of pollution control required is much less. However, the use of electricity as an alternative fuel increases the pollution control problems at the power-generating plant. Regulations relating to the environmental quality of effluents and emissions from coal generation of electricity will have impacts on the availability and cost of power for melting glass.

Process modification to utilize heat from the melting furnace for preheating the batch reduces overall energy consumption by an estimated 20 to 30%. Air emissions from the glass furnace are reduced due to the lower fuel requirement. Elimination of the need for sophisticated pollution control equipment has yet to be demonstrated.

In general, emission species from the glass furnace, with few exceptions, remain essentially the same, regardless of which fuel form or process modification is used. By and large, the volume of air emission from the furnace increases for all coal-based alternatives, whereas electric melting and batch preheat reduce exhaust volume. Future air emission standards for glass furnaces relating to NO_x , SO_x , and particulates will determine the costs of control. The choice of alternatives would be influenced by these added costs, and the potential high cost of pollution control could deter further development.

8. Iron and Steel

a. Recovery of Carbon Monoxide from the Basic Oxygen Process (BOP)

BOP off-gases, consisting largely of carbon monoxide, are highly combustible. In conventional practice spontaneous combustion with air occurs in the gas-collecting hood. Non-combustion systems prevent this air infiltration; they cool and clean the CO-rich gases without burning them and make them available as a gaseous fuel for general purposes. The recovered gas has a heating value of about 200 to 250 Btu/scf, representing 0.4 to 0.5 x 10^6 Btu per ton of raw steel. In the CO collection system, the dust is less oxidized than in the conventional combustion system, contains a smaller percentage of submicron particles, and is easier to collect. Treatment of water used in scrubbing is facilitated because of the more rapid settling characteristics that result. Solid waste disposal methods are unaffected.

Compared with a total combustion system, the CO collection system with a gas holder will cost about 60% more in capital, mainly because of the need for a separate and independent hood and scrubber for each furnace.

Because of the cyclic pattern of gas generation, the need for a gas holder of several million cubic feet capacity or larger, the land needs associated with the gas holder, and the logistical problems in piping a collected gas to end-users, we find that industry regards this source of fuel gas to be supplemental to its other fuel sources. However, if the collected gas can be utilized and credited at \$2/10⁶ Btu, the non-combustion collection system offers lower operating costs than the conventional BOP pollution control equipment.

Overall we believe that the iron and steel industry is expected to implement non-combustion collection and recovery of the fuel value in BOP off-gases in new installations built over the next 15 years. Because a large proportion of the remaining open-hearth capacity will be replaced by BOP, and the total capacity of the industry will increase at an average rate of about 2.5%/yr, BOP capacity by 1990 may be expected to increase 80-100 million tons above the 1973 level. A significant fraction of such capacity can be expected to be achieved by "rounding out" (i.e., capacity increases achieved by going from a two-vessel to a three-vessel BOP shop). Logistical factors, such as plant layout and location, are likely to have a major influence on the actual number of steel plants adopting the non-combustion recovery system. However, for every million tons of installed production capacity adopting the non-combustion system, about 4.4×10^{11} Btu are recoverable in the form of a supplemental fuel source.

b. External Desulfurization of Hot Metal

In the blast furnace the sulfur content is controlled by adding limestone to form a sulfur-bearing slag and by limiting the sulfur content of the metallurgical coke. External desulfurization is achieved by injecting sulfur-retaining reagents (e.g., calcium or magnesium compounds in an inert gas such as nitrogen) into the hot metal from the blast furnace. These compounds form a sulfide slag that must be skimmed off prior to pouring into the BOP. This latter procedure either permits limestone and coke rates to be reduced, or alternatively allows the sulfur content in the coke to be increased without charging more limestone to the blast furnace.

Since sulfur content specifications in finished steels are decreasing slowly with time, an important parameter in sulfur control is the quality of the coke (or coal) supply available to each company. When the coke contains more than 1.2 - 1.5% sulfur, we believe that external desulfurization becomes economical. Aside from coke-rate implications, external desulfurization permits a better consistency in the sulfur content of the hot metal charged to the BOP, thereby smoothing the steelmaking operation and increasing its yield.

From an environmental viewpoint, external desulfurization represents a potentially new source of air pollution, including fine carbon particles, the characteristics of which have yet to be defined. (In addition, demand for desulfurizing agents may have an environmental impact in industries producing such compounds.) From an energy-usage viewpoint, external desulfurization allows substitution of higher sulfur metallurgical coal for less plentiful, low-sulfur metallurgical coal, thus expanding the domestic reserves.

We believe that this process option looks sufficiently attractive, so that several external desulfurization installations can be expected to be built during the next 15 years.

c. Dry Quenching

The dry quench system replaces the wet one using water to quench the incandescent coke pushed from a coke oven. In the dry quench system, sensible heat from the coke is transferred to the inert gas and can then be partially recovered. The physical facilities involved in either method of quenching are physically separate from the coke ovens. The incandescent coke is pushed from the oven and falls into a tracked car in which it is transported to the quenching area. Thus the emissions which occur during the pushing operations from the ovens are altogether a different concern from the emissions which occur during quenching operations, but there can be a relationship in current design concepts, depending on the type of tracked vehicle used to transport the incandescent coke.

While dry quenching of coke is practiced in the U.S.S.R., there are no installations in the United States. Russian authors claim that dry quenching produces a higher grade coke and reduces coke rate in a blast furnace. However, this claim has to be demonstrated for U.S. coals. Moreover, less production of coke breeze is claimed for dry quenching, but many situations may exist in which this could generate a shortage of breeze for sintering plants. In addition, the physical installation is more complex than that for wet quenching, and this complexity increases the capital cost significantly. The difference between a dry coke quenching station with the associated tracked vehicle and a wet quenching station is at least \$7 million and possibly twice as much as this for an annual production of 1 million tons of coke. Moreover, it appears that a standby quenching station would be needed as a backup quench system which could add another \$2.5 million to the capital investments. Only very large plants, using several quenching towers, could waive the requirement for a standby quenching unit. The only demonstrated benefit of dry coke quenching is the significant amount of energy recovery. This energy represents about 1.1 million Btu per ton of coke, which is equal to the energy needs of the coke byproduct plant.

The iron and steel industry probably will not adopt dry quenching of coke on any significant scale during the next 15 years. This situation could change if it can be demonstrated that dry-quenched coke from U.S. coals can measurably reduce blast-furnace coke rates. Supporting experimental evidence so far is lacking.

d. Direct Reduction

New iron units (oxide pellets, lump ore, etc.) can be partially reduced in the solid state by reaction with a reducing gas mixture (CO and H_2) at temperatures ranging from 1470°F to 2000°F . These prereduced materials are also called sponge-iron or metallized materials, because up to 95% of their iron content exists in the metallic state. They can partially replace scrap in the steelmaking electric arc furnace, be charged to the blast furnace to increase its productivity, or used in the oxygen steelmaking shop in lieu of scrap.

The most advanced direct reduction technology proven to date is based on the use of natural gas or a petroleum-based hydrocarbon as the energy source. Technology based on coal employing the rotary kiln, is also available (SL/RN*, Krupp, Kawasaki), but demonstration on a large scale for acceptance in the United States is still at least several years away. A successful large demonstration is vital for widespread application of this technology in the United States.

The alternative use of coal for direct reduction purposes would be a gas-oriented process utilizing a coal gasification step to produce the necessary high-temperature reducing gases. Although the technological approaches are clear and research and development are underway, commercial demonstration of this alternative lies farther in the future because it has not proven economically attractive.

Pollution control problems with the direct-reduction electric furnace route are generally less severe than with the blast furnace route. A major factor in this respect is the elimination of the need for coke ovens. While the rotary kiln, direct-reduction electric furnace steelmaking route eliminates dependence on metallurgical coal, it consumes about 40% more energy per ton of steel than the blast furnace, coke oven, basic oxygen furnace route. Its energy conservation potential is one of form rather than quantity.

The two routes are about equally costly, in terms of both capital and operating expenses. Transportation costs and other site-specific economic conditions, together with reliability expectation differences, presently favor the traditional approach via the blast furnace for the bulk of the steel industry. Because these total cost estimates represent relatively small differences between large numbers, it will be worthwhile to re-examine this judgment periodically.

Certain locations in the world have the potential for low-cost manufacture of semi-finished steel products via direct reduction and electric furnace steelmaking, e.g., Venezuela with iron ore and surplus natural gas resources and the Middle East with surplus natural gas resources. Long-distance movement of metallized pellets, or even of semi-finished products in international trade, could become of major importance in facilities planning within the next 15 years.

In view of these findings, the industry should be expected to treat the subject of direct reduction and the production of metallized iron units cautiously. It may be more realistic to expect that the U.S. industry will import increasing quantities of metallized or partially reduced pellets within the next 15 years. While a few plants may be built, the prospects for large-scale, direct-reduction processing in the United States within the next decade do not look optimistic.

*SL/RN = Stelco-Lurgi/Republic Steel, National Lead.

9. Olefins

The major impact of the current energy crisis on the olefin industry will be to force the use of heavier feedstock in most new olefin plants. These heavier feedstocks - naphtha and atmospheric gas oil - do not give as high a yield of ethylene as do the lighter feedstocks - ethane and propane. Furthermore, the conversion of naphtha or gas oil to ethylene is more complex and requires a significantly higher plant investment than is required for an ethane-propane (E-P) plant. The heavier liquids used to produce olefins almost always contain more impurities than E-P, with sulfur being the major impurity of environmental concern. The increased sulfur content of the feedstocks increases the environmental controls necessary for the olefin facility.

Counterbalancing the drawbacks associated with the use of heavier feedstocks is a significant increase in the production of valuable byproducts over those produced when using an E-P feed. Thus, although the total energy required to produce a pound of ethylene increases with heavier feedstock, the energy required per pound of useful product decreases. Nevertheless, the estimated cost of producing ethylene from naphtha or gas oil would be about 30% higher than the cost of producing ethylene from an E-P feedstock, even though reasonable byproduct credits were utilized.

The estimated costs for environmental controls to satisfy existing or anticipated regulations fall between 0.5 and 1.75% of the cost of producing ethylene. The lower percentage is for E-P cracking and the higher percentage is for gas oil; the cost of environmental controls using naphtha feedstock falls in between. The energy requirements for environmental control are less than 0.1% of the total energy required for the production of ethylene. However, even small variations in relative pollution control costs or manufacturing costs will have a significant impact due to the size and competitive nature of the industry.

One of the main environmental impacts resulting from the use of heavier feedstocks is indirect. When naphtha or gas oil is cracked to produce olefins, a significant quantity of pyrolysis fuel oil is produced as a byproduct. If the sulfur content of the feedstock is above a certain level, the sulfur content of the byproduct fuel oil will be high enough to preclude its use as a fuel without further desulfurization or flue gas desulfurization at the point of use. Economical technology is not currently available for the direct desulfurization of the pyrolysis fuel oil produced and flue gas desulfurization is also not economically attractive for multiple combustion units. Therefore, most olefin producers would prefer to choose heavy liquid feedstock materials with a low enough sulfur content to ensure that the sulfur content of the byproduct fuel oil would be acceptable as a fuel under present regulations. This preference puts undesirable restrictions on the choice of feedstock. Alternatively, the olefin producer could desulfurize the feed in a petroleum refinery-type operation prior to cracking. This would put the non-integrated chemical companies at some disadvantage to the petroleum companies integrated with olefin production.

Other technology is being developed for producing olefins from other feedstocks and for utilizing conventional feedstocks more efficiently. Developmental work is underway to utilize vacuum gas oil, vacuum residues or resids, crude oil, and coal as possible feedstocks for olefin production. Developmental work is also being done on the thermal cracking of naphthas in the presence of hydrogen to improve the yields of ethylene. The olefin industry started this developmental work so that it could utilize these less desirable, but more available, feedstocks. It is generally believed that this new technology will not have significant impact on the olefin industry within the next 10 years.

At present there are no federal standards on the control of fugitive emissions from an olefin facility. Since olefins - ethylene, in particular - have a very strong odor, the industry has apparently already controlled these emissions. If very stringent controls on fugitive emissions were promulgated, the economic impact of meeting them could be significant. Stringent control of fugitive emissions would most likely have the same type of impact on all the process options studied as well as on the technology that is still in the development stage.

Regulations controlling emissions from sulfur-recovery facilities have an impact on the olefin producers in their choice of sulfur-recovery technology to be incorporated in the olefin production facility. The technology required to meet the current regulations is well established and is not considered a serious economic burden.

10. Petroleum Refinery

The five industry process changes assessed in this study included:

- Direct combustion of asphalt in heaters/boilers;
- Asphalt conversion by hydrocracking (H-oil);
- Asphalt conversion by Flexicoking®;
- Internal power generation; and
- Hydrogen generation by partial oxidation.

These options were evaluated within the context of "typical" existing refineries representing actual refinery clusters existing in the Petroleum Administration for Defense (PAD) districts selected. Each of the above options achieves an energy form value improvement.

Within the framework of the comparisons set forth, we find that the implementation of the above changes will have a small impact on the control of refinery wastewater. The effect on the characteristics of the treated effluent, the type of treatment required to conform with regulatory requirements, and the cost of wastewater treatment would not preclude the selection of any of the alternatives. Asphalt conversion by Flexicoking® has the highest wastewater treatment cost, and the cost penalty is about 25% of the

total pollution control cost and about 7% of total process operating costs, including pollution controls.

There are, however, some identifiable impacts in regard to air pollution regulations, particularly SO₂ emissions. All of the options involve utilization or conversion of petroleum residues which contain a disproportionate part of the sulfur found in crude oil. Removal of this sulfur to limits set for SO_x emissions has a significant impact on those options which involve the direct combustion of asphalt (vacuum bottoms) for heaters/boiler or power generation. In the case of asphalt combustion for heaters or boilers, operating costs for flue gas desulfurization (FGD) account for more than half of the total operating cost. This is indicative of why petroleum refiners have preferred to comply with sulfur dioxide regulation by fuel blending rather than by installing FGD systems on process heaters and boilers. The reason FGD is not generally applied in refineries is that there are numerous small (by electric utility scale) sources within a specific refinery which require control. FGD systems for the capacities normally encountered with process heaters have high unit costs.

"Internal power generation" is similarly impacted by the high cost of a small flue gas desulfurization system. A potentially attractive modification to internal power generation is the integration of electric power generation with process steam generation through the use of a topping cycle (steam pressure reduction with back-pressure turbines). This approach could conserve total energy in the refinery in contrast with the other options which just upgrade form value. Hence, some movement in this direction may be mandated by FEA, economics notwithstanding. Asphalt combustion would be a natural choice of fuel for this scheme, were it not for the high cost of stack pollution control. Again there is a case for developing small source FGD technology, perhaps utilizing typical refinery resources such as CO, H₂, amine plants, and sulfur reduction processes.

A possible alternative to asphalt combustion in a refinery is to sell the asphalt to an electric utility for burning in large boilers equipped with FGD systems. This would reduce the unit cost of pollution controls due to the improved economies of scale, but would entail cost or technical difficulties in handling and transporting the asphalt. Also, this may be in conflict with efforts aimed at reducing the amount of petroleum used by electric utilities.

The impact of EPA regulations on the residuum upgrading processes, such as H-Oil and partial oxidation, is not unreasonable and, in most cases, the additional control required represents an incremental change to an existing sulfur recovery system.

The choice of alternates for heavy resid conversion is particularly dependent upon the type of crudes processed at a given refinery and the particular markets for asphalt, coke and distillate fuels. Furthermore, the impact of pollution regulations is not particularly great for these options; consequently, pollution regulations are not seen as an impediment in the application of these technologies.

11. Phosphorus

Phosphorus and its compounds are important requirements for many industries, and the establishment of new plants to support the growth of phosphate products is assured. The principal requirements are in fertilizers, food chemicals, industrial phosphates, and detergents. Two different technologies are currently practiced, and they serve two largely different market sectors:

- The fertilizer requirement will continue to be supplied in the conventional manner by digestion of phosphate rock with sulfuric acid in the so-called wet-process route. The process produces phosphoric acid containing many impurities, but it meets the requirements set by the fertilizer industry.
- Elemental phosphorus, food-grade chemicals, and industrial phosphates requiring high-purity phosphoric acid are based on elemental phosphorus produced in an electric furnace.

From an overall energy standpoint, the wet process is much more efficient than the electric furnace process. It requires about 16×10^6 Btu/ton P_2O_5 product, about one-fifth of the 79×10^6 Btu/ton required for the electrothermal route (when electric power is converted to an approximate fossil fuel equivalent using 10,500 Btu/kWh).

a. Use of Byproduct Sulfuric Acid

The wet-process industry can operate with purchased byproduct sulfuric acid rather than with sulfur which is converted on-site. The price of sulfuric acid for such an operation would probably be negotiated with the result that the cost of phosphoric acid product would be competitive with that from an ordinary wet-process acid system. In addition to purchasing sulfuric acid, a plant without an on-site sulfuric acid plant would require steam normally supplied by the acid plant. This steam, amounting to about 3 million Btu/ton P_2O_5 , might be generated with an on-site steam boiler, or it could be purchased from a utility if the plants are adjacent. Pollution problems directly associated with phosphoric acid would be the same; the pollution problems normally part of the sulfuric acid plant would be eliminated.

b. Strong Acid Process

An alternative for wet-process phosphoric acid production is to operate the digestion system at phosphoric acid concentrations of about 50% P_2O_5 . Evaporation of the product acid is not required under these conditions. The digestion system must be operated at a temperature of about 212°F and the calcium sulfate is separated as the hemihydrate. The process is claimed to be competitive with the standard wet-process system and would be particularly attractive at an integrated fertilizer production site where additional process units could use the steam no longer required for evaporation. Evolution of fluorides from the digester could be expected to be more severe than with the standard wet-acid system, but the evaporator vent stream is eliminated. On an overall basis, pollution control problems could be expected to be about the

same as with the standard wet-process system. The adoption of a strong acid process with the use of byproduct sulfuric acid would be attractive on an energy basis.

c. Cleanup Processes vs. Furnace Acid

To supply phosphoric acid for food-grade chemicals and industrial phosphates, immediate expansion of the electric furnace industry is not foreseen because of the high capital costs required, the shortage and cost escalation of electric power, and the uncertainty of costs for pollution control. As requirements for detergent phosphates increase, it is likely that the opportunity for their production by cleaning wet-process acid will be exploited. There are two methods of modifying the wet-process system so that the phosphoric acid produced is clean enough for production of detergent phosphates:

- 1) the chemical cleanup route, relying on sulfuric acid to digest phosphate rock, and
- 2) the solvent extraction systems, using hydrochloric acid for digestion of phosphate rock.

The economic viability of incorporating one of these methods with a wet-process plant, instead of production from elemental phosphorus, depends to a large extent on the price at which phosphate rock, sulfur, or hydrochloric acid can be made available to a given plant. Compared with the 79 million Btu/ton phosphoric acid required in the base line electric furnace route, both cleanup alternatives are energy-efficient, requiring 3 to 16 million Btu/ton phosphoric acid, depending on whether or not the heat of combustion of sulfur is credited. The base line electrothermal phosphoric acid and both cleanup routes to phosphoric acid generate wastewater streams which must be treated prior to discharge. Some of the pollutants present in the treated effluent are common to all three alternatives, while others are characteristic of specific alternatives. In general terms:

- All three alternatives produce treated effluents which contain low (but not insignificant) amounts of soluble phosphates and fluorides.
- The treated effluents from the elemental phosphorus alternative and the chemical cleanup alternative both contain moderately high concentrations of sulfates.
- The treated effluent from the wet process-solvent extraction alternative is generally devoid of sulfates, but contains an extremely large quantity of calcium chloride. The wastewater also contains a moderate amount of n-butanol solvent.

Economically feasible wastewater treatment control technology is available for each of these alternatives. In our assessment, the high concentration (13.6%) of calcium chloride present in the treated effluent from the wet process-solvent extraction alternative will render it unsuitable for discharge into most receiving streams. For estimation of pollution control costs we assumed that the most feasible disposal method for this waste stream is deep-well injection (where permitted).

The elemental phosphorus route alternative (furnace acid) is the most expensive, while the wet process (chemical cleanup) alternative is the least costly. The costs are sufficiently close to one another so that plant-to-plant variations and site-specific factors could easily upset the relative cost ratios. In general, it can be concluded that no one process has a very significant treatment cost advantage over the other. It should be noted that deep-well disposal, although perhaps economically feasible, is only a viable option in regions where geological formations are favorable and local and Federal regulations permit such disposal. If the calcium chloride brines were required to be converted to calcium chloride salt, the operation would be energy-intensive. Furthermore, the major markets for calcium chloride are in road deicing, especially in the northern tier of States and Canada, and in the cement industry where it is used to remove sodium and potassium as the chloride. In either instance the potential for high concentrations of chlorides entering ground or surface waters has not been decreased from the potential that exists at the plant, although the distribution and localization would change. In fact, road deicing would result in a much wider potential distribution with probably greater impact on drinking and surface waters. Obviously, the disposal of brines is a significant problem. The cost of wastewater treatment (as arrived at within the bases of this study) is a relatively small percentage of the total production cost.

None of the wastewater treatment processes are highly energy-intensive, and even the highest wastewater treatment energy consumption is a very small fraction of the total process energy consumption.

d. Solid Waste Related to Wastewater Treatment

All three systems process significant amounts of wastewater treatment sludge. In each case the sludge contains large amounts of calcium fluoride and calcium phosphates and cannot be disposed of indiscriminately. Estimated quantities of wastewater treatment sludge are:

- Elemental phosphorus route
84,750 ton/yr sludge wet basis;
- Wet process - neutralization/precipitation
80,700 ton/yr sludge wet basis;
- Wet process - solvent extraction
45,500 ton/yr sludge wet basis.

Although the mass of sludge from the solvent extraction alternative is about one-half that of the other alternatives, it is more environmentally objectionable due to the high concentration of soluble chemicals which could rapidly leach from the sludge.

We conclude that, from a water pollution standpoint, the wet-process, sulfuric-acid, chemical cleanup (neutralization/precipitation) alternative is the most favorable from an energy/environmental viewpoint. The wet process-solvent extraction is the least favorable, solely due to the serious calcium chloride brine disposal problem.

12. Pulp and Paper

Of the many processes considered in the pulp and paper sector, four were selected for detailed evaluation in the Industry Assessment Report, namely:

- Rapson effluent-free kraft process;
- Alkaline-oxygen pulping;
- Thermo-mechanical pulping; and
- De-inking of old news for newsprint manufacture.

a. Rapson Effluent-Free Kraft Process

The first commercial installation of the Rapson effluent-free kraft process is presently under construction at the Great Lakes Paper Company in Thunder Bay, Ontario. The process is designed to produce none of the BOD, suspended solids, and color that characterize effluents from the chloride/caustic bleaching system used with the conventional kraft process. (It does not affect the solid waste or air emissions, however.) The process maintains all the desirable physical characteristics of the product and reportedly can be retrofitted into existing kraft mills.

When compared with the conventional kraft pulping and bleaching methods, the technical/economic evaluation of the Rapson process indicates that it would provide:

- Significant energy savings (7 million versus 2 million Btu/air-dried ton, respectively);
- Cost savings (\$290 vs. \$259 per air-dried ton, respectively).

Further, since much of the overall water effluent associated with bleached kraft pulp manufacture originates in the bleach plant, the elimination of effluents from this source, as contemplated by the Rapson process, would cause a major reduction in the overall water effluent from an integrated kraft pulp and paper mill.

Should the first installation prove to be technically and economically successful, the new process could greatly alleviate the water pollution problems confronting a large segment of the U.S. pulp and paper industry. It might well be included in the design of all new bleached kraft pulp mills and retrofitted into existing ones as a more convenient and less costly way of avoiding the color produced by traditional kraft pulp bleaching processes. The alternative color-removal technique, lime treatment, entails a lower initial investment, but the potential annual savings with the Rapson process could return the additional capital expenditure in 1 or 2 years.

Results from the first commercial installation should be available within 2 or 3 years to validate the postulated benefits of the Rapson process. If the experimental results are confirmed, the process could be adopted by a significant portion of the bleached kraft industry within the next decade.

b. Alkaline-Oxygen (A-O) Pulping

The first A-O pulp mill has been installed by Weyerhaeuser in Everett, Washington. If the process is successful, adoption of the A-O pulping process by the industry could have some long-range beneficial effects; particularly the alleviation of much of the air and water effluent problems presently confronting conventional kraft mills. Although it would have no significant effect upon solid waste characteristics, the total reduced sulfur (TRS) and the odor problem typically associated with the conventional kraft process would be eliminated, and the color problem associated with the conventional kraft pulping and chlorine/caustic bleaching processes would be reduced by about 50%.

On the basis of available data, the A-O process is not a direct substitution for the kraft pulping process, because the resultant product has inferior strength characteristics. More promising areas of possible product/process substitution would be in applications for bleached chemical pulp (both kraft and sulfite) in which high strength properties are not essential. These potential applications comprise less than 50% of the total bleached chemical pulp usage.

In view of the early stage of its commercial development, sufficient "hard" data are unlikely to be available within 2 or 3 years to assess the technical and economic viability of the A-O process. The single installation presently in the startup stage constitutes less than 0.5% of the total U.S. bleached pulp capacity; accordingly, any beneficial impact from its commercial development will not be felt within the next 3 years. Furthermore, because of the extended lead time needed for the design and construction of a mill using new technology, the successful development of A-O pulping is likely to have only a minimal impact upon the industry within the next decade.

c. Thermo-Mechanical Pulping

As an alternative to chemical processing, thermo-mechanical pulping (TMP) is one of three methods by which mechanical techniques (grinding) are used to reduce wood raw material to papermaking fiber; the other two are stone ground-wood and refiner mechanical pulping (RMP).

TMP, a recently developed alternative technique, has been successfully demonstrated in a few commercial installations. Its wider application is assured because of overall cost savings in the manufacture of finished product. This results from the fact that the physical strength properties of TMP pulp are superior to those of conventional RMP. Most paper products are made from a blend of chemical and mechanical pulps; chemical pulps are stronger, but more expensive than mechanical pulps, so papermakers use as much of the latter as they can without unduly weakening the product. The substitution of TMP for RMP permits a higher percentage of mechanical pulp and thus a lower cost.

The picture from an energy standpoint is somewhat different. In terms of energy intensivity, TMP and RMP are about equal, but both are higher than chemical pulp. As a result, the higher proportion of mechanical pulp that is made possible by the TMP process also slightly increases the amount of energy used in making the finished product.

Water pollution resulting from the manufacture of the finished product (made from a combination of chemical and mechanical pulps) is little affected by TMP, although the BOD load is slightly higher (about 20%) than with the conventional RMP process. Air emissions are not a problem with any of the mechanical pulping processes, so the industry's acceptance of the TMP process would not affect the characteristics of the mechanical pulping operation. However, as less chemical fiber would be required in the finished product, a smaller volume of air emissions would be produced in its manufacture.

The wider use of TMP could alter the disposal pattern of sawdust and shavings, which are part of the solid waste from a lumber manufacturing operation. These materials are presently burned for their heat value, sold as animal litter or, in some cases, used as cellulosic raw material in pulp manufacture. The higher pulp strength properties attainable via TMP vs RMP would permit greater use of these byproducts in higher added-value applications.

Water pollution effluents could be affected by a significant modification of the TMP process - chemi-thermo-mechanical pulping (CTMP). In this process, small amounts of chemicals (1 to 2% caustic and sodium sulfite) are added to the wood chips prior to their mechanical attrition. The purpose of the chemical is to solubilize some of the organic adhesive that binds the papermaking fibers, thus facilitating their separation, while maintaining maximum strength characteristics.

While there is little commercial experience to quantify the effect of CTMP on energy and pollution, it is reasonable to postulate that there would be a reduction in energy usage in the defibering operation and that additional dissolved organic material would appear in the water effluent stream. Further, it seems probable that the low quantity of organic materials (5-10%) and chemicals (1-2%) appearing in the water effluent would make it economically unattractive to burn the "spent liquor" to recover its heat and chemical value, as is normally done in "full chemical pulping." Unfortunately, sufficient data are not available at this time to quantify more precisely the pollution consequences of this variation of the TMP process.

d. De-inking of Old News for Newsprint Manufacture

The de-inking of old news for newsprint manufacture uses only about 25% as much energy as that required for the alternative manufacturing processes used to produce the combination of chemical and mechanical pulps present in de-inked pulp. Our contacts with mills that plan to install de-inking facilities indicate that they expect no problems in complying with water effluent emission regulations; thus, there appears to be no potential conflict with the regulations as the result of broader application of de-inking. Further, since the amount of chemical fiber that is added to the de-inked fiber in the manufacture of recycled news may be reduced or entirely eliminated, air emissions

associated with the production of kraft pulp* would be much less of a problem in recycled newsprint manufacture.

With regard to solid waste, the use of de-inking would entail no significant change at the plant site; the benefit that would accrue from recycling newsprint would be to alleviate the solid waste problem facing major metropolitan areas. Waste paper constitutes 30-40% (by weight) of our total municipal solid waste, and about 15% of the waste paper is newsprint. Accordingly, the de-inking of old news could make a measurable reduction in the amount of solid waste in cities.

13. Textiles

There are many potential "energy-conserving" unit operations being introduced commercially or under development, some with EPA sponsorship. In this study we defined "model" textile mills which would maximize the use of energy-conserving "unit process" options as follows:

- Advanced aqueous processing (referred to as "advanced processing") in which the sequence of unit operations is designed to minimize water and energy use; and
- Solvent processing in which a solvent (such as perchloroethylene) or solvents are used rather than water to transfer chemicals to and from the fabric.

a. Integrated Knit Fabric Mill

(1) Advanced Aqueous and Solvent Processing

In advanced aqueous and solvent processing overall energy use is decreased by 50%, although electricity use is increased through substitution of air extraction for conventional drying. The same substitution, together with more efficient operation of the heat-set tenterframes** (drying frame), reduces natural gas use considerably. Reduction in steam use is achieved through maximum water economy and recycle of rinsewaters.

Solvent processing shows a 70% reduction in overall energy use, although steam is still required for evaporation and recovery of the solvent and for stripping the solvent after the finishing operation.

Advanced aqueous processing does not reduce the pollution loading because the same chemicals are used, but the lower hydraulic load reduces pollution control costs and improves the efficiency of effluent treatment. All solvent

*There are alternative methods for making chemical fiber that do not have an air emission problem, but the quantity of these materials used is much smaller than that of kraft pulp in this application.

**Although waste heat recovery per se is outside the scope of this study, we have included a heat recovery unit attached directly to the tenterframe which preheats the incoming air as a process modification.

processing practically eliminates the water pollution potential, but the chemicals removed from the solvent during recovery represent a solid waste disposal problem. Recovery of solvent for recycling must be very high for economic reasons, but the solvent losses may still represent an air pollution problem. Solvent recovery systems are designed by the manufacturers to meet present air pollution control regulations and environmental health regulations, but there is considerable concern on the part of EPA and OSHA that chlorinated solvents are a particular hazard which may require more stringent regulation. This factor may be a potential deterrent to the adoption of solvent processing, although at the present time the technical limitations are probably more important.

The capital investment required for advanced aqueous processing is not a great deal higher than that for the conventional technology; therefore, this would not be the determining factor in introducing the technology to a new plant or processing line. However, because of the small leverage of energy costs compared to capital costs, there is no major advantage in terms of reduced product costs which might encourage the adoption of this technology at a rapid rate throughout the industry. The incremental capital costs for advanced processing over the base line are adequately repaid from reductions in operating costs and pollution control costs. Therefore, whenever new or replacement capacity is required, advanced processing does have an economic (and environmental) advantage. It also has lower energy costs, thus providing the manufacturer with some protection against future fuel and energy price increases. It is also feasible for the unit operations which make up the advanced processing to be adopted piecemeal by existing plants with a consequent energy saving and lowering of pollution control costs.

(2) Solvent Processing System

Similar comments apply to the solvent processing system, but there are some additional reservations. Equipment for solvent processing is commercially available and being used in textile mills, generally in more specialized applications where solvent processing is essential because of the nature of the chemicals used or because an improved product is obtained. At present its most widespread application is in scouring of knit goods. An all-solvent processing line would have the advantage of completely eliminating the wastewater effluent, but as yet, the technology is not sufficiently well demonstrated to show that an all-solvent processing line is commercially feasible. The dyeing step is particularly troublesome; in spite of much work, there are still severe limitations in the type of dyes and range of colors that can be applied from a solvent medium. In particular, the dyeing of polyester by solvent methods has not been adequately demonstrated, and this is one of the most important fibers being used in knit fabric today.

b. Integrated Woven Fabric Mill

Advanced aqueous processing offers a 57% reduction in energy consumption by reduction in the use of electricity, steam, and natural gas. Reduced electricity and steam consumption results from better water economy and the use of less energy-intensive technology. Lower natural gas use comes from optimization of the tenterframe operations for drying and heat setting which

includes the addition of a heat recovery unit on each tenterframe. This reduction is a result of optimization of 23 different unit operations in a particular sequence for the processing of a 50/50 polyester/cotton fabric. Many textile mills have much more diversified processing and the energy savings may be less, but we would still expect them to be substantial.

It is assumed that the wastewater effluent from base line and advanced processing are both treated by biological methods. As with the knit fabric mill, the decreased hydraulic load will reduce treatment plant size and costs. The use of polyvinyl alcohol (PVA) size and its recovery reduces the hydraulic load and the pollution loading (BOD and COD). Potential air and solid waste effluents are minor. Some organic compounds (degradation products of finishing chemicals) escape with the flue gas, but with good operation the levels of organics fall below the levels set by regulation. Other minor amounts of finishing chemicals may end up as a tarry residue in the tenterframe, which is periodically removed for disposal.

Adoption of advanced processing does not greatly reduce product cost because of the high capital investment required for a new woven mill. The incremental costs of capital investment for advanced processing over conventional processing in a new mill are relatively small and show a good payback in terms of lower energy use and resource recovery. The lower pollution loading from PVA recovery and reduced water use will also reduce the size and cost of the biological treatment plant for the wastewater effluent. Therefore, adoption of advanced processing appears likely for much of capacity replacement and expansion. PVA recovery is attractive economically and environmentally, and will be used if it can be shown to be applicable to a wider range of fiber combinations.

C. IDENTIFICATION OF CROSS INDUSTRY TECHNOLOGY

Within the industry sectors investigated in these studies, several generic types of process technologies or problem areas were identified as follows:

- Applications of preheating,
- Sulfur removal from hot gases,
- Use of fluidized bed,
- Heat recovery,
- NO_x emissions,
- Use of oxygen,
- Use of electric furnace, and
- Use of solvent.

We recognized that some of these "common type" process concerns had applications in fields outside the scope of this study, as further discussed below.

1. Preheating

Preheating of solids prior to processing has been identified as an energy-conserving process change. In the glass sector, agglomeration and preheating of the charge offer the potential of reducing dust carryover from the glass-making furnace and somewhat reducing NO_x and SO_x emissions from high-sulfur fuel because less fuel is used. In the cement sector, the suspension preheater/flash calciner was shown to be an energy-conserving process change with the potential of reducing NO_x emissions because less fuel is used. In addition, we are aware that in the industries examined preheaters are being considered or used in:

- producing of blast furnace coke from coal, and
- preheating ferrous scrap charges to electric furnaces or basic oxygen furnaces.

Preheaters take a variety of forms, including rotary kilns, shaft furnaces, fluidized beds, batch devices, and the like, and each is designed with a particular application in mind. Due to lower fuel usage, one can generally expect reduced SO_x , NO_x , and particulate emissions.

2. Sulfur Removal from Hot Cases

In several process alternatives using gasified coal, particulates and sulfur removal are accomplished at low temperatures, and the clean product gases are then reheated to the temperature desired for the chemical reaction. Examples are found in direct reduction of iron ore, glassmaking, and ammonia manufacture. Considerable energy may be saved if particulates, heavy metals, and sulfur could be removed at high temperatures. Such technology producing a hot, clean reducing gas (consisting largely of H_2 and CO) would have applications in many other industrial sectors either as a clean fuel or as a feedstock such as for substitute natural gas, methanol manufacture, and hydrogen generation (via the water gas shift reaction) in petroleum refining. Overcoming cooling/reheating of such gas streams reduces energy use and its concomitant pollution.

3. Fluidized Beds

Fluidized and ebullated beds are being considered as new processing techniques in several industries. Examples include:

- flash calciner/suspension preheaters in the cement industry,
- fluidized bed cement process,
- hydrocracking (H-Oil reactors) in the petroleum industry,
- flexicoking which is a new process in the petroleum industry for converting heavy bottoms to light liquids and gas. In this process sulfur contained in the bottoms combines to form H_2S which, in turn, can be converted to elemental sulfur using conventional technology.

Since first applied commercially in 1942 to the catalytic cracking of heavy petroleum fractions, fluid-bed technology has experienced widespread application including:

- fluid coking,
- metallic sulfide and pyrite roasting,
- direct reduction of iron ore,
- phthalic anhydride production,
- lime production, and
- nuclear processing (denitrification, reduction, hydrofluorination, and fluorination of uranium; separation of plutonium from uranium).

Other applications, such as a plasma-heated fluid bed for phosphorus production, an electrically heated bed for HCN production, coal gasification, and fluidized-bed steam boilers, have also been proposed. Fluid beds range from single-stage units to multi-stage devices, as exemplified by the various configurations of preheaters and flash calciners shown in the Cement Industry Report (Volume X). The fluidizing media can be gas (as in a suspension preheater described in the cement report), or liquid (as described in the H-Oil ebullated bed). One of the major advantages of a fluid bed is close temperature control and high heat-transfer rates. Thus, when used as a preheater for solids rather than a kiln or reverberatory furnace, one can accomplish combustion and heat transfer at much lower "flame temperatures" and thus reduce NO_x emissions. Where limestone is part of the mixture being preheated (as in cement manufacture), sulfur emissions are also kept under control.

4. Heat Recovery

Recovery of waste heat from solids discharged from furnaces or kilns can yield energy savings as exemplified by cement kilns (preheating of air) and dry quenching of coke in the steel industry to generate steam or a hot gas stream. As discussed under dry quenching in the steel industry report, environmental problems anticipated are particulate emissions from hoppers and hot valves as the solids are discharged. In general removing heat from solid materials will entail controlling particulate and fugitive emissions.

5. NO_x Emissions

All other things being equal, NO_x emissions can be expected to increase from many processes for a variety of reasons including:

- fuel switching from gas or oil to coal; coal will contain some fixed nitrogen and generally requires a greater amount of excess air; both factors will normally lead to higher NO_x emissions;
- fuel firing with air preheating which leads to higher flame temperatures, leading to greater NO_x emissions; and
- fuel firing with oxygen-enriched air which generally leads to higher flame temperatures and greater NO_x emissions.

The environment, health, and ecological impacts of NO_x need to be better defined with respect to obtaining more quantitative knowledge for establishing appropriate emission regulations. Control of NO_x emission in an economic way will demand new technology. Technology for abatement of NO_x emissions of the 200 ppm range is discussed in the Fertilizer Industry Report under nitric acid manufacture.

6. Use of Oxygen

Oxygen use can be expected to increase in many industrial sectors as a result of attempts to reduce energy use and costs. When used to enrich air with fossil fuel firing, NO_x concentrations can be expected to increase, but total off-gas volume should decrease (assuming everything else remains constant). NO_x emissions can be reduced by limiting excess air, while still ensuring complete combustion as discussed in the cement report. When oxygen is used in place of fossil fuel (as in flash smelting of copper concentrates), the flame temperature is not expected to increase and consequently there should be little or no increase in NO_x emissions. Several other direct firing situations not studied in this project may benefit from air enrichment.

7. Electric Furnaces

With concerns about pollution control in fossil fuel-fired furnaces, electric furnaces are being considered as an alternative in many industry sectors. An example discussed in these studies is the electrically heated glass furnace (Glass Industry Report, Volume IX). We are also aware that applications of electric furnace technology is also being considered in other new applications as in the iron and steel industry (direct reduction) and smelting

of copper concentrates. Use of an electric furnace in place of a fossil fuel-fired furnace reduces substantially the volume of gas and its particulate loading. Moreover, the SO_2 emissions can be many times eliminated by replacing a high-sulfur fossil fuel by electric energy. While a glass plant may mitigate its environmental problems with an electric furnace, the environmental problem is passed back to the power plant, especially those using high-sulfur coal. Considering typical power plant thermal efficiencies of about 30 to 40%, we found in the glass industry study that more fossil fuel is used in the electric furnace when comparing a fossil fuel fired furnace against the system consisting of a power plant with electric furnace. However, this difference in fossil fuel requirements is small and total uncontrolled sulfur emissions are little affected. However, we feel that such results cannot be generalized to other industry sectors because furnace efficiencies depend on a variety of factors, including size, design, operating temperatures, need for water cooling to prevent refractory erosion, degree of endothermic versus exothermic reactions during processing, and the like.

8. Use of Solvent

In two sectors (textiles, and pulp and paper) use of solvent processing in place of aqueous processing is discussed. Solvent processing involves some new sources of pollution (hydrocarbon or solvent emissions in gas streams). Additionally we have discussed the application of solvent extraction in the copper sector (use of liquid ion exchange resins) and manufacture of clean phosphoric acid via the wet acid route.

V. PROCESS RESEARCH AREAS

Potential areas of research identified in the process sections include the following:

1. Aluminum

We suggest that consideration be given by the Government (not necessarily EPA) to the possibility of undertaking or sponsoring materials research in the field of producing titanium diboride cathodes suitable in quality to permit long operating life in the Hall-Heroult cell environment. This development would have a dramatic effect on energy savings in the aluminum industry; in addition, there would be favorable environmental effects by reducing the emissions from power plants per ton of aluminum produced as well as potentially reducing CO emissions from alumina cells.

2. Ammonia

In assessing the pollution aspects of the coal alternative, it will be necessary to measure and trace the materials of environmental interest in coal gasification. This has been attempted and there are some preliminary data available.

In design of recycle streams, such as the soot recycle to the gasifier, it is apparent that certain trace elements may tend to build up since they may not be able to escape. This could apply, for example, to volatile compounds found in coal such as arsenic, lead, boron, and fluorine. More information is needed to determine if this recycle buildup will be a problem.

3. Cement

We identified several areas in which additional data or information would have been helpful. This forms the basis of our recommendations for additional research into existing or future processes and industry practices in the U.S. portland cement industry. They are:

- Develop and implement a commercial-scale test program to be implemented on one or more flash calciner-equipped rotary kiln cement-making facilities to characterize the gaseous and particulate emissions. Of particular interest would be the emissions from a flash calciner-equipped rotary kiln operating with a bypass of a considerable amount of the combustion gases in order to eliminate alkalis.

- Develop and implement a test program at a number of cement plants with clinkering facilities employing long rotary kilns, suspension preheaters, or flash calciners which burn coal as the fuel. Coal of various sulfur levels should be tested to determine their effect on operation and the level and nature of sulfur in the gas, dust, and clinker. The benefits which derive from the physical and/or chemical cleaning of coal to reduce pyritic sulfur levels in coal for cement manufacturing could also be quantified.
- Develop and implement a program to sample and analyze dust from various kiln systems, especially those burning coal, in order to correlate the trace elements, especially the heavy metals, in the dust wastes, with the presence of those elements or constituents in the raw materials and coal burned.
- Develop and implement a program to analyze and study ways of using waste kiln dust (for example, as a soil conditioner or plant nutrient, or as the primary or major raw material feed component to the fluidized-bed cement process).

4. Chlor-alkali

Since the process changes in themselves are not expected to create new environmental problems, but rather reduce the amount of pollution generated by the chlor-alkali industry, we recommend that any research development or demonstration effort be oriented to accelerate and evaluate the introduction of the newer, less polluting, energy-conserving technology.

5. Copper

The research we recommend in the following areas of the copper sector would provide more information about these processes and might resolve the problems preventing the adoption of these energy-conserving and environmentally beneficial technologies.

a. Impurity Distribution

An understanding of impurity distributions is necessary for determining emissions of trace metals and the need for pollution control or process change to prevent these emissions. Such impurity distribution studies include:

- The behavior of impurities in each process, their distribution in gas, slag, matte, and metallic phases, and forms in which impurities leave the process units (as particulates, slag, etc.);
- In oxygen-enriched smelting, an examination and definition of the changes in impurity distributions resulting from higher temperatures;
- Impurity distributions in hydrometallurgy; and
- Impurity forms in waste streams from pyrometallurgical and hydrometallurgical processes.

b. Impurity Removal

- Methods for removing impurities (e.g., Bi) from blister copper via modified fire-refining procedures. If impurities can be removed from copper, one-step smelting can be used. This would significantly decrease fugitive SO₂ emissions from smelters;
- Methods for removal of arsenic from elemental sulfur produced by SO₂ reduction;
- Techniques for impurity removal from concentrates via pretreatment.

c. Feedstocks

- Verifying the applicability of new smelting technology to impure concentrates;
- Verifying the applicability of new smelting technology to smelt calcines from roasters.

d. Metal Recovery/Separation

- Developing methods for separation and recovery of metals from flue dust; in particular, the treatment of flue dust containing arsenic, antimony, lead, and bismuth;
- Methods for the recovery of precious and trace metals from hydro-metallurgical residues;
- Methods for the recovery of copper (also zinc and lead) from slag flotation tailings;
- Methods for reduction of copper in slag during pyrometallurgical slag cleaning, e.g., carbon reduction in a rotary converter;
- Conversion of ferric oxide sludge from hydrometallurgical processes to a form suitable for use in other industries.

e. Miscellaneous

- Developing high-temperature refractories for oxygen smelting;
- Developing better process control techniques to reduce manpower requirements, particularly in pyrometallurgy, which would reduce hazards resulting from uncontrollable fugitive emissions.

6. Fertilizers

For nitric acid plants, it would be beneficial in terms of energy conservation to use processes other than catalytic reduction for NO_x control. Fortunately, such other processes require less capital and lower operating costs. Thus, the industry will likely opt for such alternatives of free choice

and will not require outside influence. In the process examined, control appears adequate at steady state but not adequate during startup and shut-down. Also, the NO_x pollution control device is complex and may have to be shut down, even though the basic plant continues to operate. Methods of alleviating these problems are worthy of further study. Moreover, it would be useful to study the applicability of these new processes to control NO_x emissions from sources other than nitric acid plants.

For fertilizer drying, the most appropriate action is to disseminate information on techniques for using bag filters in conjunction with oil-fired dryers.

7. Glass

A proven economically viable system to control glass furnace emissions of SO_x and particulates must be developed if cost-effective pollution control is to be obtained. Such a system is required if any of the coal-related processes is to be utilized.

The feasibility of a batch-preheating process modification needs to be demonstrated to stimulate implementation of this technique for energy conservation and pollution reduction. (The technical and economic feasibility of a preheat-agglomerate process modification is the subject of EPA's RFP No. DU-75-A-291.)

Demonstration of the technical feasibility of producing quality glass with economic furnace operation and life, using direct firing of pulverized coal, would aid in conserving energy by utilizing the less critical form of fuel with a minimum of intermediate steps and their cost in dollars and energy.

8. Iron and Steel

Five specific areas have been identified in this study where additional research is needed:

- a. The possibility of cyanide formation under the following circumstances should be investigated:
 - injection of nitrogen during external desulfurization, and
 - continuous recirculation of a CO-N_2 mixture on incandescent coke during dry quenching.
- b. Quantitative measurements of fugitive and source emissions of carbon monoxide with non-combustion BOP gas collection systems should prove the acceptability of these hoods, including during the transition periods at the beginning and end of the blow.
- c. A comparison of available equipment (lances, bells, etc.) for external desulfurization should be made. At the same time, the exact nature of the gaseous effluents should be determined according to the exact type of reagent used.

- d. An increase in the quality of coke due to dry rather than wet quenching has been reported in the Russian literature. Should this be the case, a more efficient operation of the blast furnace would result and allow substantial savings, both in terms of coke rate and furnace productivity. In order to substantiate this claim using U.S. coals, a demonstration program is needed.
- e. The chemistry of the rotary kiln (e.g., SL/RN, Krupp, Kawasaki) is still not well known. The pollution implications mentioned in this study represent best engineering judgment and lack actual proof. The composition of the off-gases and the leaching properties of the coal, ash, and fine metallic discarded particles should receive the attention of research organizations.

9. Olefins

The olefin industry can benefit from additional research on the removal of sulfur from the cracked-gas stream. This stream contains hydrogen sulfide, some carbonyl sulfides, and varying percentages of diolefins and other reactive compounds which tend to foul the acid gas-removal system. As indicated in the olefin report, this problem is now being handled by depropanizing the cracked-gas stream before acid gas is removed by scrubbing with diethanolamine. A method of removing the sulfur compounds and acid gases from the cracked-gas stream in the presence of diolefins (i.e., before the depropanizer) would be of significant economic benefit to the olefin producers.

Naphtha and atmospheric gas oil feedstocks produce significant quantities of byproduct pyrolysis fuel oil. If the feedstock material used in the olefin plant has a sulfur content above a certain concentration, the byproduct pyrolysis fuel oil has sulfur levels too high for its environmentally acceptable use as a fuel without flue gas desulfurization. These byproduct fuel oils also contain substantial amounts of unsaturates as well as other reactive materials which tend to polymerize and form gums on handling. These present problems when attempting to desulfurize the oils. It would be desirable to develop an economically attractive process for desulfurizing the pyrolysis fuel oil to a level where it would be environmentally acceptable as a fuel. At present, most olefin producers limit the sulfur content of their feedstock to circumvent this problem. As noted earlier, however, this limitation severely restricts their choice of feedstocks.

10. Petroleum Refining

As a result of this assessment, two technology areas have been identified. Through added research, each could increase energy conservation in terms of form value availability. The first would have as an objective improving the reliability and reducing the cost of flue gas desulfurization, especially in the size range below 50 MW equivalent.

The second is concerned with developing rugged hydrocracking catalysts which can withstand the poisons normally present in petroleum residues, or alternatively an economic residual demetallization process. The objective in this case would be to increase space velocities (more activity) and yields. Solvent de-asphalting of hydrocracker feedstocks is used for this purpose, but

the energy requirement for solvent recovery is substantial. Technology improvements in these areas could increase refinery yields of clean fuels without sacrificing environmental quality.

11. Phosphorous

The wet process requires disposal of about four tons of gypsum per ton of P_2O_5 product. The gypsum disposal problem can be managed to meet environmental regulations through placement in settling basins for which precautions are taken to prevent leaching into groundwaters or excessive surface run-off. The gypsum wastes contain much of the fluorides which are a component of the phosphate rock and which have been removed from gaseous streams by scrubbing. The long-term containment of the large volumes of fluoride-containing gypsum solids is a problem analogous to that facing the steam-electric generating industry in its disposal of sludges from flue gas desulfurization and is an area where research and development is needed to delineate the disposal methods most acceptable to regulatory agencies. Many schemes have been proposed to make use of the low-value byproduct gypsum, such as for wall board. Except in unusual economic settings, most of these have not proven viable, but they do represent a potential research area.

12. Pulp and Paper

Areas identified for further research demonstrations include the following:

- The Rapson effluent-free kraft pulping process is the most significant and imminent process industry change from the standpoint of major energy and pollution implications. Therefore, EPA should encourage its development by participation and, if necessary, provide support in bringing it to commercial fruition. Participation would furnish EPA with environmental, energy, and cost data which could then be made widely known to the industry.
- The alkaline-oxygen (A-O) process would apply to a much smaller segment of the industry and thus lacks the potential impact of the Rapson process in terms of reducing the industry's pollution problems. On the other hand, the Rapson process would alleviate only the water effluent problems, while the A-O process would alleviate both the air and water pollution problems presently associated with the major alternative manufacturing method - namely, kraft pulping and bleaching. We believe that EPA should participate in joint evaluation of this process.
- The thermo-mechanical pulping (TMP) process is well established. While it may be beneficial to obtain more precise analytical data on its energy usage and pollution characteristics, all reports to date indicate that (except for a 20% higher BOD load than with the conventional RMP process) there is no significant difference between the current and "new" technologies with regard to energy usage or pollution.

Hence, the TMP process does not warrant as much encouragement and assistance in commercial evaluation as the two previously listed process changes or the modification of the TMP process (chemi-thermo-mechanical pulping - CTMP). Because CTMP offers both significant advantages in increasing the available supply of pulpwood and an inherently greater pollution problem than any of the other mechanical pulping processes, an accurate evaluation of its commercial potential appears appropriate when such data become available.

- The de-inking of old news for the manufacture of newsprint presents an opportunity to save energy with no potential pollution problem. Broader commercial application should be supported, because it could reduce the amount of municipal solid waste.
- Alternative drying techniques and displacement washing appear to offer possibilities for significant energy savings with beneficial effects on industry emissions. The potential energy savings appear to be sufficiently attractive in paper drying to warrant further pilot evaluation of the more promising techniques. Displacement washing has reached commercial operation in a few installations, so it does not require further development effort; nevertheless, its impact upon energy and pollution considerations should be quantified to verify the postulated benefits.

13. Textiles

- a. Polyvinyl alcohol recovery has been shown to have economic and energy-conserving advantages. So far it has only been demonstrated on polyester/cotton sheeting. Its applicability to other products and fibers should be demonstrated.
- b. Energy saving is possible if the amount of water used for washing can be reduced substantially. This would require an evaluation of washing efficiency in the various types of washer used in the industry and in the new units now available. Concurrently with this, a program is required to demonstrate improved instrumentation and techniques for monitoring washing in the various process steps and to determine when adequate washing has been achieved.
- c. Water reuse appears to be limited at present by the variety of chemicals used in each process step. Development work is required to minimize the amount of chemical used in each step and to make the different chemicals more compatible with each other so that processing steps may be combined and/or additional water recycled.
- d. Recovery of chemicals other than PVA and caustic soda has not yet achieved any major application, although work is in progress to evaluate water and chemicals reuse in dyeing operations. Additional methods for recovery of dyes, which are expensive and cause color problems in waste treatment plants because of their refractory nature, should be investigated.

- e. A major obstacle to the demonstration of an all-solvent processing system is the lack of acceptable techniques for solvent dyeing, particularly of polyester and cotton/polyester blends. Pilot-scale studies should be carried out to demonstrate the advantages and limitations of the best processes described in the literature. Similar work is also required to demonstrate the applicability of solvent finishing systems.
- f. It appears from the data available that solvent losses from an all-solvent system are at present only marginally acceptable and may be in excess of future occupational health or environmental regulations. A study of an all-solvent system is required to define where and how solvent losses occur and to develop better control technology for solvent emissions. Otherwise, we believe this problem may represent an obstacle to further development of solvent processing.

VI. FUTURE REASSESSMENT OF PROCESS OPTIONS

As the various factors influencing the choice of process options change with time, the evaluation system devised here should allow for easy reassessment of the proposed process options. For example, capital investments and operating costs were identified separately for the pollution control technology and for the basic process operations. Similarly the unit consumption of labor (man-hr/ton of product), power (kWh/ton), fuel oil (10^6 Btu/ton), etc. was specified for both the base line and alternative technologies. Thus, as the investment costs and operating cost factors (e.g., labor, fuel, and power) change with time, these new values can be incorporated into the re-analysis of the process options. Similarly should the impact of new or advanced pollution control technology wish to be investigated, the investments, operating costs, and energy consumption can easily be incorporated within the framework of a reassessment study and compared with the base line technology as delineated in this report. Furthermore we believe that the methodology used can be applied to other industries and form the basis of a framework examining energy use and pollutional consequences of new technology.

Since the analysis was performed on the basis of selecting a region of the country and using applicable average cost factors within the industry, the applicability of such new technology to other regions, sectors, or time frames can also be easily accommodated by incorporating the appropriate new cost factors, (e.g., labor rate, fuel cost, power cost, raw material cost, etc.). Similarly, the impact of state or local environmental constraints can also be examined where the differences from Federal regulations appear significant.